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Management Practices Evaluation

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This report provides information on the water quantity and quality effectiveness of all commonly used management practices. The practices are discussed as they apply to urban and agricultural areas, and are broken into groups of related practices. Each practice is described and the purpose is discussed, followed by a brief discussion of the target pollutants for which the practice should be used. Planning and design considerations, including costs, are presented. This is not a design manual, but references are given for design specifics. Information on effectiveness of practices was obtained from original data collection, literature review, and individuals experienced in the use of particular practices.

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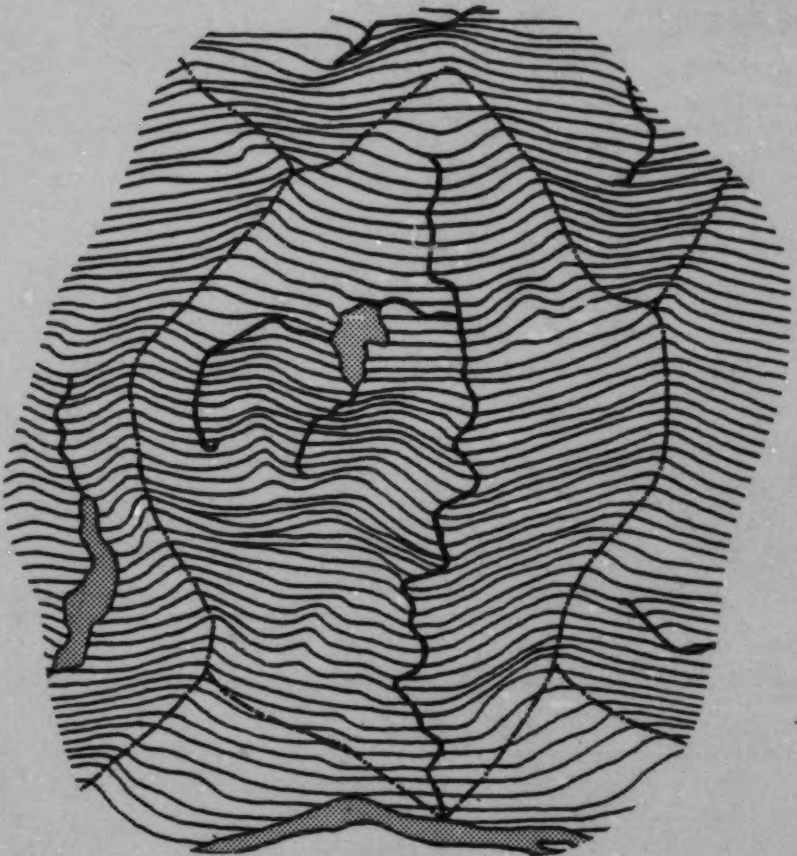

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SURFACE WATER MANAGEMENT:
MANAGEMENT PRACTICES EVALUATION

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ABOUT THIS REPORT

There is a continual need among water managers for timely data on the effectiveness of various management approaches. This need is particularly strong in the Twin Cities Metropolitan Area because of the 1982 Metropolitan Area Surface Water Management Act (Ch. 473.875 to 473.883), which requires comprehensive surface water management on a watershed basis.

This report was funded by the U.S. Environmental Protection Agency (EPA) to provide information on the effectiveness of all management practices commonly used in this Region. It is one of several reports prepared by the Metropolitan Council with EPA funds to assist water managers in watersheds and communities to prepare plans and implement programs aimed at resolution of surface water problems.

The format used in this report is quite simplified. The management practices (MP) categories are discussed as they apply to urban and agricultural areas. Within these two large areas, MPs are broken into "families" or groups of related practices, such as detention or agricultural conservation. Each MP is described and the purpose is discussed, followed by a brief discussion of the target pollutants for which the MP should be used. The MP is then evaluated for its effectiveness relaive to water quality, and its planning and design considerations, including costs, are presented. It must be emphasized here that this is not a design manual, but rather a compilation of known information on the effectiveness of certain approaches that can be used to control nonpoint source pollution. In most cases references are given for design specifics.

The information presented in this report was collected from literature, from the Nationwide Urban Runoff Program (NURP), and from qualified individuals. Whenever possible, the information presented was determined under conditions similar to those of Minnesota: cases in which conditions differ markedly will be noted. In some cases information was derived through computer simulation or though laboratory experimentation. It is often difficult to compare data from different studies since few provided adequate design or application specifics. In many cases values are given in a range that represents a likely value.

Cost data should similarly be used with care. Assumptions used to determine costs in various categories such as labor or materials are usually variable by geographic areas. Costs cannot always be directly compared since varying design and implementation assumptions can drastically alter costs.

Urban cost data have all been converted to the Engineering News Record (ENR) index value of 4,000, unless otherwise noted. In some cases costs will not have changed according to the ENR assumptions. Data which were no dated in a publication were assumed to reflect the average cost from the month of publication.

Agricultural costs were not converted to a standard index, but are rather reported as provided by the data source, usually just a statement of the reference year. The ENR index was not applied because of the incompatibility of agricultural activities with the items forming the index basis.

The report was written by Andrea Haak and Gary Oberts. Haak served as a civil engineer intern with the Metropolitan Council's Natural Resources Program during 1983. Oberts is a senior environmental planner with the Council's Natural Resources Program.

PART A. URBAN

BASICS

LAND USE PLANNING

DESCRIPTION AND PURPOSE

Land use planning directs development activities to appropriate areas and encourages the retention of natural drainage features. The purpose of land use planning is to protect receiving waters from increased pollution rates caused by urbanization. Land use planning controls development by establishing zoning and subdivision regulations which define environmentally sensitive areas and establish limitations on the types and intensities of development. Planning stresses the importance of considering environmental costs in the predevelopment stage, with emphasis on prevention rather than correction of water quality problems.

TARGET APPLICATIONS

Urban lands generally stress water bodies more than nonurban lands. Urbanization increases impervious surfaces, reduces infiltration and promotes high levels of activity. Land use planning can be used to implement a variety of MPs to prevent increased pollutant loadings associated with urbanization. Suspended solids, oxygen-demanding substances, nutrients and toxic materials all represent the target pollutants that land use planning is intended to reduce. Land use planning is most effective for developing urban areas though comprehensive planning practices can also be applied during redevelopment of existing areas.

EFFECTIVENESS

The effectiveness of this broad category is dependent on the type of planning being implemented. Land use planning incorporates a variety of MPs to reduce pollution loading. Comprehensive coordination of MPs is much more effective than solving problems as they arise.

An EPA study estimated the TSS reduction associated with implementing a comprehensive stormwater management plan at 68 percent (Athayde and Waldo, 1977). This plan included a combination of floodplain zoning, flood control structures, channel improvements and source erosion and runoff controls.

A second study compared a well planned development with a poorly planned development in the Lake Tahoe region (Lynard et al., 1980). The well planned development went through the planning procedures described in the following planning considerations section. Regulations were set up to limit the intensity of the development and encourage the use of erosion control MPs during construction. The approximate TSS yield was found to increase 100 percent for the well planned site and over 3,000 percent for the poorly planned site.

PLANNING CONSIDERATIONS

Land use planning involves a comprehensive view of physical characteristics and the activities the land is capable of supporting. Intended land uses should be defined and their relationship with the physical characteristics should be analyzed. These studies should provide the information used to determine the ordinances or regulations required to protect water quality.

When developing a land use plan, it is necessary to identify physical characteristics such as soils, geology, slopes, drainage, hydrology and access. These physical characteristics should be used to determine the types of development suitable for the site. Development should be limited in critical water related lands such as floodplains, wetlands, steep erodible soils, poorly drained soils and shorelands.

Once a site has been analyzed for the level and types of development that can be supported, an economic analysis should occur. Public needs and desires for different land use activities should be determined. A land use limitation versus desired use comparison should be done on a cost basis to determine the feasibility of developing the land for a specific use.

When considering a specific plan, the effects beyond the planning region should be considered. For example, detaining stormwater downstream may cause higher flood levels downstream in an unregulated area, as will the discharge of water from an uncontrolled development into a well planned development.

Regulatory requirements are used to control land use and encourage environmentally sound planning. State and local agencies can adopt and enforce ordinances to control stormwater runoff pollution. Regulatory power is, however, rarely used exclusively to control nonpoint source pollution. Most regulations are multipurpose, not only developed to preserve water quality, but also to control flood damage, preserve land, recharge water supplies and protect aesthetic amenities.

Three land use control methods include conservation/preservation zoning, land acquisition and control of public services. Conservation/preservation zoning means sensitive water related lands are zoned to restrict development to activities that will not endanger the water resource. Designated areas often include wetlands, woodlands, aquifers, recharge zones, steep slopes, floodplains, shorelands and soils with high water tables. Zoning critical areas establishes permitted uses, prohibited acts and encourages the implementation of appropriate MPs to deal with potential environmental problems.

For example, septic tanks might be prohibited in zones with high groundwater, or a minimum percentage of vegetation might be required in highly erosive areas. Land use ordinances or floodplain ordinances are typical examples of regulations applied to achieve zoning of critical areas. A more general approach would be to require compliance with a set of water quality standards, wherein the choice of control methods would be up to the developer as long as he remained within the required runoff quality and erosion standards.

The controlling agency may use the right to acquire land as a method of controlling the development of an area. By acquiring land to preserve natural floodways, infiltration areas, and wetlands, a runoff system can be preserved while surrounding areas are developed. The land requirements for maintaining a runoff system must be determined before development occurs. Land purchasing costs can be defrayed by various means of financing, but the cost to the community will still be high. Since the purchase of land optimumly is done before development,the community generally has a weak tax base and, therefore, has little money to spend.

An alternative to purchasing land is to impose conservation restrictions to limit land use. In Minnesota, the Metropolitan Agricultural Preserves Act sets up a voluntary program wherein a contractual agreement is set up with the landowner not to develop land for a minimum of eight years to preserve land for agricultural use, while providing benefits and protection to the landowner in the form of legal protection and property tax breaks. Other methods that preserve land without purchasing it, but compensate landowners for restricting their use, can be developed.

A controlled growth plan can be implemented by the time-phased construction of municipal services. Development can be channeled into suitable areas and discouraged in areas that will adversely affect water quality by controlling the extension of sewer and other public services. Subdivision ordinances support the planning schedule and provide a method to monitor growth.

Three ways to control development methods include environmental impact assessment, standards for runoff and erosion control, and promotion of natural drainage features. Requiring an environmental impact assessment encourages the developer to be more conscious of the environmental effects of the project. Conditional development approval based on the conclusions of the environmental assessment assures that water quality problems from development are minimized.

Permission to develop can be dependent on the compliance with technical standards for controlling runoff, erosion and sedimentation. Each site should be reviewed to assure that the development method (construction erosion control) complies with the water quality goals before a permit will be issued. Many ordinances can be established to support permit requirements. One example would be a grading ordinance, which regulates cuts, clearing of vegetation and sets revegetation standards.

Development can be encouraged to preserve natural hydrological processes by requiring that the water balance remains close to predeveloped conditions. The developer has a choice of methods, but retaining natural drainage features is the most cost-effective way. Use of natural drainage features would include maintainance of undisturbed land, preservation of wetlands to be used as infiltration areas and buffer zones, and preservation of the natural system of rivers, creeks and ditches for controlling overland flow.

Land use planning will not be useful unless a method of enforcing regulatory requirements is included with the various ordinances. Civil and criminal penalties can be invoked to encourage compliance with ordinances and regulations. Fines or other penalties designed to punish violators should be strictly enforced. Poor enforcement leads to low levels of compliance. Also, a formal inspection program should be established to ensure that the land use plan proceeds as intended after initial activity declines.

DESIGN CONSIDERATIONS

Land use planning includes an infinite combination of MP alternatives. Costs will vary with the site, the approach taken during construction and the regulations set up by the planning agency. Costs of avoiding water quality and quantity problems through effective planning are expected to be much lower than the cost of correcting existing nonpoint sources caused by lack of comprehensive land use planning.

The Lake Tahoe study of an environmentally planned development calculated total costs of using planning. The estimated planning costs were $220 per acre, and total costs of both planning and construction erosion control were calculated to be $290 per acre. It was not determined how much these initial costs saved in future control devises (Lynard et al., 1980).

In some cases, land use planning can save money. The Woodlands, a Texas development, used natural drainage features to reduce erosion and flood problems. By taking advantage of the natural system, the developers were able to dispense with a conventional runoff system. Using the natural drainage system cost about 50 percnet less than a comparable conventional system (Lager et al., 1977).

Land use planning is easily done before urbanization begins since natural drainage features are still intact. Planning the development of land which has not been urbanized allows greater flexability of growth and retention of natural features. Land use planning can be implemented for redevelopment of existing areas, but is less effective since natural features have already been altered and often erosion and runoff problems already exist.

WETLANDS

DESCRIPTION AND PURPOSE

A wetland has been defined as a tract of low, wet land where "the water table is at, near or above the land surface long enough each year to promote the formation of hydric soils and to support the growth of hydrophytes, as long as other environmental conditions are favorable" (Hickok et al., 1977). Wetlands improve discharge water quality by trapping or transforming pollutants using physical, chemical and biological processes. These natural sinks for contaminants can be used as components for wastewater and stormwater treatment systems.

TARGET APPLICATIONS

Wetlands provide natural detention facilities. Three benefits of wetland detention are treatment of stormwater, slower runoff velocities and reduction of flow volume.

- Trapping sediments usually will result in reductions in suspended solids, nutrients and heavy metals. These pollutants are removed physically (sedimentation, filtration, adsorption), chemically (decomposition, chemical adsorption, complexing), and biologically (organic uptake).
- Reduced flow velocities decrease streambank erosion. As a detention facility, large runoffs are detained, thus reducing erosive flow levels.
- Flow volume decreases by evaporation and transpiration losses. Infiltration can occur in a wetland, but outflow can also occur depending on groundwater characteristics. Caution must be exercised so as not to attribute infiltration to every wetland.

EFFECTIVENESS

Studies done on a wetland in Wayzata (Hickok et al., 1977) and on wetlands as a function of watershed size (Oberts, 1982) concluded that wetlands provide a valuable service in improving water quality. Wetlands are effective removers of suspended solids and moderately effective for phosphorus and heavy metals. Other materials that are removed include oils, nitrogen species, organic compounds, bacteria and viruses.

Seasonal factors influence the effectiveness of a wetland ability to act as a treatment component. High levels of water were found to submerge wetlands, creating anerobic conditions and greatly decreasing its removal efficiency. The largest variance in removal efficiency was found with the nutrients. During the spring season, a wetland may become a source of nutrients. Other studies have indicated that wetlands may seasonally become a source of most pollutants previously removed. Under optimum management conditions, the following reductions can be associated with wetland treatment:

Pollutant	Percent Removed from Water
TSS	90%
TP	50-75%
COD	50-75%
Nitrogen	50%
Heavy metals	75-90%

Source: Hickok et al., 1977; Metropolitan Council, 1983a; Oberts, 1981.

The effectiveness in reducing water quantity has also been studied. A water balance done on the Wayzata wetland (Hickok et al., 1977) found evapotranspiration made up 25 percent of the wetlands water outflow. In this case, groundwater flow provided an inflow source, but in other areas infiltration could reduce outflow further.

PLANNING CONSIDERATIONS

Artificial wetlands can be built, but in Minnesota this is usually unnecessary. It is much easier to save an existing wetland than to create an artificial one. Existing wetlands should not be drained or filled without the impact on the water drainage system being analyzed.

Wetland reclamation may be considered when dealing with an area that was previously a wetland. Unfortunately, once a property owner spends money to drain a wetland, it will be more difficult to compensate him for the land. For this reason, wetlands do not make a good MP choice for fully develped urban areas.

Wetlands can provide a valuable resource for improvement of water quality. The protection of natural wetlands is done using ordinances or through DNR regulations. Minnesota state laws presently protect only certain classifications of wetlands of certain sizes. An environmental assessment should be done for any action effecting a protected wetland. A comprehensive watershed plan should establish which wetlands are essential natural controls in the water system, and local programs should develop protective ordinances for those wetlands not protected by DNR.

When the need to retain an area as a wetland outweighs an owner's desired use of that land, just compensation should be made. One method is public acquisition of the land. A second method is to allow some type of tax credit for keeping the wetland in its natural state.

Advantages and disadvantages should be considered when planning to use a wetland to improve water quality. The following table attempts to identify these considerations:

Advantage	Disadvantage
o Low cost compared to conventional treatment system: Indirect cost = land, O & M = minimal.	o Land based treatment uses 4 to 10 times more land than conventional treatment system.
o Wildlife habitat.	o Breeding ground for mosquitoes.
o Effective water pollutant removal; stromwater runoff treatment.	o Decrease taxable productive alternative land use.
o Groundwater interaction.	o Additional MPs may be needed: additional initial cost and O & M.
o Surface water control; impact reduction.	o Generate possible odors.

DESIGN CONSIDERATIONS

Manipulation of many key factors can be planned to improve water quality through increased wetland efficiency. The key design factors to consider in association with wetlands include:

- Velocity, flow rate;
- Water depth and fluctuation;
- Detention time;
- Circulation and distribution patterns;
- Turbulance and wave action;
- Seasonal and climatic influences;
- Groundwater conditions; and
- Soil permability.

The following practices are designed to manipulate the key design factors of a wetland:

- Flow routing will maximize effective contact between water and wetland soils and vegetation. This practice is best used on wetlands that are chaneled. The purpose is to diffuse the flow through the wetland. Common methods are diversion berms, level spreaders, ditches or piping.
- Harvesting vegetative growth may help remove nutrients that cause periodic phosphorus or nitrogen loading of the discharged waters.
- Water level controls can be used to prevent extreme high or low water levels by controlling inflow/outflow. One method to use is a baffled weir outlet, which controls the flow rate of water discharged from the wetland. This metering devise can be made of wood at little expense and has the

added benefit of skimming floating debris. A detention pond before the wetland can be used to store large volumes of runoff water to be discharged to the wetland at a slower rate after pre-settling.

- Caution must be used, however, since a wetland can be overloaded with sediments from stormwater inflows. Presettling incoming stormwater can remove sediment loads. Discharges from high erosion areas such as construction sites should be settled upstream from wetlands to remove the excess sediment load from the runoff water.

- Aeration may be considered when dealing with wetlands. Wetlands can turn anaerobic on a seasonal basis. This decreases some of the more desirable biological activities, and can generate strong odors. Decreased oxygen levels in the wetlands discharge waters may have a detrimental effect on the receiving body since many pollutants are resuspended or resolubilized under anaerobic conditions. Seasonal diversion away from wetlands can be considered.

As an MP, wetlands are inexpensive. The initial cost is the cost of the land. There are few O & M costs when using a natural system. When using additional practices to maximize efficiencies, the costs increase accordingly.

EDUCATION

DESCRIPTION AND PURPOSE

Education and information programs are an essential part of a successful comprehensive surface water management program. The purpose of these programs is to convince the public of the need for nonpoint source pollution control. Education programs are conducted to encourage the use of appropriate MPs by developing public awareness, promoting involvement and providing technical information.

TARGET APPLICATIONS

Education programs can be aimed at controlling essentially all pollutants. Information programs should be applied constantly when education will help prevent future or control existing nonpoint source pollution. Education programs promote the use of MPs by planners, and developers to reduce sediments during construction; inform the general public and community administrators of the importance of housekeeping methods; or instruct lakeshore owners on methods that control phosphorus.

EFFECTIVENESS

The effect of information and education programs on water quality cannot be quantified, but they are expected to provide some water quality and quantity improvements by providing awareness and encouraging the use of pollution control measures.

PLANNING CONSIDERATIONS

Education is best used as a preventive measure that provides the ground work for the use of other MP methods. Information and education programs are best used to inform and train various groups of the need for MP applications. They teach contractors, developers and consultants the benefits of applying on-site construction and erosion control MPs; communities the benefits of following good housekeeping MPs; and farmers the benefits of conservation farming.

There are no regulatory requirements promoting the use of education, but without it the full impact of a pollution source may be ignored and MPs could be misused or forgotten.

DESIGN CONSIDERATIONS

In the Metropolitan Council 1982 Nonpoint Source Pollution Technical Report (Oberts, 1982) information and education programs for owners of property directly tributary to the lake estimated the costs to range $1,200-6,200 per lake. A Wisconsin watershed study (SEWRPC, 1980) analyzed the cost for a regional or county level comprehensive education program. They determined the cost of one staff person, materials and support would be approximately $40,000 per year to reach a population of 25,000. There would be no formal O&M costs, though the program would be reapplied yearly at the same cost. In some cases after the initial introduction periods the cost of the yearly program may be reduced to provide a sustentive level program.

A well organized, effective education program is not easy to develop. People have known about water quality, erosion and flooding problems for decades, yet often remain apathetic to actions meant to curb these problems. The first step of an educational program is to promote awareness of the problem, then acceptance of appropriate MPs as possible solutions. The goal of achieving involvement and active use of MPs as a solution to nonpoint source pollution problems can best be achieved when education begins before pollution problems develop.

HOUSEKEEPING

STREET SWEEPING

DESCRIPTION AND PURPOSE

Street sweeping refers to the mechanical cleaning of street surfaces. The most commonly used types of street sweepers are broom (mechanical) sweepers and vacuum sweepers. Broom sweeping has a gutter broom that moves material to a main pickup broom which sweeps material to a storage hopper. Vacuum sweeping uses suction to remove materials from the street surface. The material is wetted in the sweeper and deposited in a vacuum chamber. The purpose of this MP is to reduce pollutant levels on street surfaces, improve the aesthetic quality of an area and decrease air pollution (dust control).

TARGET APPLICATIONS

Target pollutants generally removed as street debris are solids, and to a lesser extent COD, BOD, TKN, TP, metal residues and pesticides.

The application rate of this MP depends on the effectiveness level desired. Since street sweeping is most effective at removing larger particles, a minimum sweeping schedule should be planned around the loading of large volumes of pollutants. Minimum recommended times are spring (immediately after snowmelt) and fall (leaves). To provide any significant reduction in pollution loadings such as in commercial or high volume traffic areas, sweeping must be done on a weekly or daily basis.

EFFECTIVENESS

The effectiveness at reducing adverse water quality impacts is a function of sweeper efficiency and loading factors. Sweeper efficiency functions include number of passes, cleaning frequency, equipment type, equipment speed, pavement type, surface conditions, operator skill and public awareness.

- Number of passes--One study stated that one pass removed 50 percent solids and two passes provided 75 percent solids removal (Lager et al., 1977).
- Cleaning frequency--Streets cleaned weekly or daily in certain areas (see later discussion) might provide a reduction in surface water pollution. Streets cleaned less frequently have a negligible value for water quality improvement but do have aesthetic value.
- Equipment type--Mechanical sweepers are more efficient on large particles while vacuum sweepers are more effective in removing small particles. Mechanical sweepers may miss fine solids which make up only six percent of the total solids, but 25 percent of oxygen demanding materials. Usually smaller particles are most detrimental to water quality.
- Equipment speed--Sweepers should be run between 3.5-5.0 mi/hr. for top efficiency (Lager et al., 1977).

- Pavement type--Concrete can be cleaned better than asphalts or oils and screen surfaces.
- Surface conditions--(see Street Repair section). Pavement in good condition is easier to clean and breaks apart less than pavement in poor condition.
- Operator skill--Skillful operators can get the maximum performance from a machine. The effectiveness of street sweeping depends on the operator´s ability to cover the maximum amount of street surface, especially around parked cars.
- Public awareness--Vehicles left on the street during sweeping operations greatly decrease the amount of street surface covered. For example, a 50 percent vehicle compliance means that the solids reduction is cut in half.

Pollutant loading factors are functions of area characteristics, land use activities, pavement conditions, type of road, accumulation rate and rainfall.

- Area characteristics--The loading depends on area characteristics such as land use, air pollution, topography.
- Land use activities--Commercial and industrial areas contribute larger loads than residential areas. Loading rates increase with more intense road use. Other activities such as construction may increase the loading to a road.
- Pavement conditions--Pavements in poor condition accumulate pollutants faster than those in good condition (see Street Repair section).
- Type of road--Oils and screens tend to contribute larger loads than asphalts and concretes.
- Accumulation rate--The accumulation rate is dependent on land use. The more traffic using the road the faster the accumulation rate.
- Rainfall--Frequency, duration and intensity of precipitation control the load accumulation time span.

The effectiveness of a street cleaning MP is dependent on the relationship between loading and sweeping factors. The following street surface removal efficiencies and typical values for a weeky to daily sweeping program (Stanley Consultants, 1976):

Pollutant	Percent Removal
Solids	0-80
TP	0-40
BOD_5	0-75
TKN	0-60
Heavy metal	0-75
Pesticide	0-60

A very important point must be introduced here. The recently completed EPA Nationwide Urban Runoff Program (NURP) concluded that although good street surface pollutant reductions can be achieved with active street sweeping, these reductions do not translate into water quality improvements in receiving waters (U.S. EPA, 1982). In fact, they found that frequent sweeping might increase loads because of the removal of the "armour" or larger particles that ordinarily shelter small particles and their associated pollutants. In short, street sweeping has been shown to be effective at removal of large particles on street surfaces for aesthetic purposes, but essentially ineffective at water quality improvement. The exceptions to this finding are areas of greatly accelerated accumulation, such as high traffic commercial and industrial zones, and areas directly tributary to lakes wherein the lake essentially acts as a receiving conduit. Also, in northern climates, spring debris and fall leaf removal are important.

PLANNING CONSIDERATIONS

Application of this MP should be determined by weighing watershed factors. For the above mentioned reasons, this method is not recommended as a particularly effective pollution reduction MP. An infrequent sweeping schedule is recommended for its highly valued aesthetic improvements to the environment and for removal of large-grained particulates. A minimum semi-annual schedule is recommended for residential areas; sweeping should be implemented in the spring to reduce winter sand and accumulated debris and in the fall to remove leaves. Frequent sweeping is recommended for critical areas, lake drainage basins where runoff flows directly into surface waters and high load zones, usually industrial and commercial areas.

Parked cars may be the biggest factor in sweeper ineffectiveness. Parked cars decrease efficiency by the factor of compliance. If 50 percent of the cars remain parked and obstruct the sweeper's operation then solid reduction will drop 50 percent. Figure 1 shows the difference that parking restrictions can mean for solids removal.

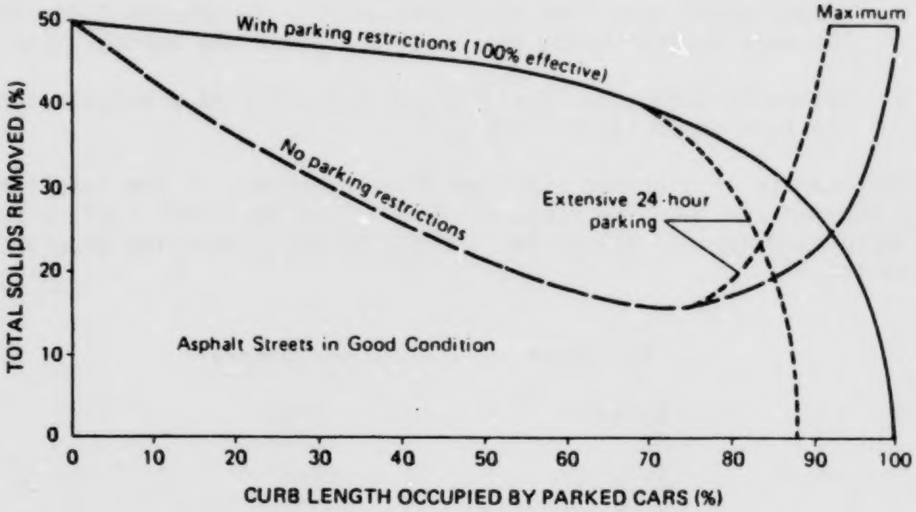


Figure 1. Effects of Parking Restrictions During Street Cleaning on Asphalt Surfaced Streets in Good Condition. (From Pitt, 1979).

Efficiency of street sweeping may also be improved by choosing the equipment that is most effective, modifying the work habits of the operators, and improving the time of the sweeping operations.

DESIGN CONSIDERATIONS

Street sweeping is one of the most common MPs used because of the ease of application and visibility in fully developed areas. The street sweeping MP has no land requirements and is nonstructural, both factors are desirable when dealing with a developed urban area.

Choosing the correct type of sweeper is important. A vacuum sweeper is more expensive but with a hose attachment can be used as a catch basin cleaner, thus capital cost can be split between MP techniques. However a vacuum sweeper loses its effectiveness when pavements are wet. Vacuums may also have difficulties with clogged air hoses and filters from clay particles. Broom sweepers tend to be slightly less expensive than vacuum sweepers. Most cities in the Metropolitan Area own and use broom sweepers on a semi-annual basis. They can be operated while roads are wet and are extremely effective at removing large particles, though their effectiveness in removing small particles is poor. Often these small particles are what pollutants of concern adsorb to. Broom sweepers tend to stir up dust which increases atmospheric loading. Equipment performance is dependent on the operator and maintenance skill. For optimizing debris removal and minimizing costs, trained and skilled personnel are required.

Sweeping costs may vary greatly by area. The variance in operation and maintenance costs is due to labor costs and to the level of support equipment operational during sweeping. Labor cost make approximately 65 percent of the total O & M costs. Following are ranges of sweeper costs:

Initial cost (Moreau and Lapointe, 1979; personal communication with Minneapolis Public Works)

Broom	\$40,000 - \$80,000
Vacuum	\$60,000 - \$90,000

O & M (Oberts, 1982)

Metro Area \$20-300/curb mile

STREET MAINTENANCE

DESCRIPTION AND PURPOSE

The purpose of this MP is to reduce street surface pollutants. Increasing street maintenance and repairs represents a nonstructural MP. Pavement conditions have been correlated with the amounts of pollutants found on the street. Vehicles driving over rougher roads have more particulate matter shaken from them. Solids might also originate from pavement deterioration. Poor street conditions can cause other MPs such as street sweeping to become less effective.

TARGET APPLICATIONS

Target pollutants are solids and associated pollutants. The optimal level for street maintenance should be determined by comparing maintenance costs against the physical and environmental benefits of a repaired road.

EFFECTIVENESS

The effect on water quality is difficult to determine. It has been reported that good street repair has a positive effect on cleaning efficiencies and/or street loading. Figure 2 relates pavement condition with solids loading rate for different land uses:

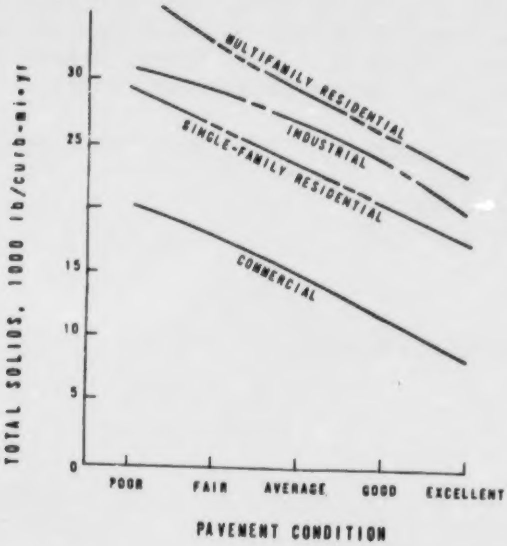


Figure 2. Pavement Conditions Versus Solids Removal (From Lager et al., 1977).

PLANNING CONSIDERATIONS

Street maintenance is best applied to provide a usable transportation surface. Generally the overall effect of street maintenance on nonpoint source pollution is not sufficient as the only reason for requiring higher maintenance levels.

DESIGN CONSIDERATIONS

A local public works agency is responsible for street repairs. For more information contact the Minnesota Department of Transportation or city public works agency.

COLLECTION SYSTEM MAINTENANCE

Collection system maintenance is the upkeep of storm or combined sewer systems. Major practices are catch basin cleaning and sewer flushing. The purpose is to remove pollutants from sump areas where they tend to accumulate and to maintain maximum flow to treatment and disposal sites, while minimizing overflows due to local flood conditions.

Regular inspection of the collection system is a required step for the implementation of their maintenance program. Inspection of each individual system should indicate the required maintenance frequency.

CATCH BASIN CLEANING

Description and Purpose

A catch basin is a chamber or sump, usually built in the curbline of a street to allow storm water to enter a sewer or subdrain. Most catch basins have a sediment sump at this base designed to retain sediments. A catch basin is installed to minimize sewer clogging by trapping coarse debris.

The purpose of catch basin cleaning is to remove settled debris before they are flushed into the collection system by a runoff event. By removing retained sediments the pollutant loadings to receiving water should be reduced.

Target Applications

The major pollutants removed by a catch basin are grit and larger debris. Catch basins only efficiently retain particles larger than 2000 microns. Once a catch basin is filled with sediment it becomes inefficient. It has been reported that once a sump is 40-50 percent full any inflow could have a flushing effect and actually generate sediment loading while passing through the catch basin (Lager et al., 1977). Cleaning frequency should be estimated by considering the sediment loading rate and volume of the sump. Areas with high solids loading such as beaches, construction sites and unstable embankments will require more frequent catch basin cleaning. At the very least, all catch basins should be cleaned once a year.

Effectiveness

Catch basins have been estimated to retain up to 57.5 percent of the solids and 17.8 percent equivalent BOD (Lager et al., 1977). The actual effectiveness due to cleaning a catch basin will depend on the type of material in the basin and the frequency with which the basins were cleaned. Catch basins are relatively ineffective at retaining pollutants with a small particle site.

Planning Considerations

Catch basin cleaning is best used when existing basins fill up with sediments. It does not appear to be a cost effective method of reducing nonpoint source pollution, therefore, catch basin cleaning is usually applied at limited frequencies as a way to maintain existing basins.

Design Considerations

There are several methods to clean a catch basin: hand cleaning, bucket cleaning, educator cleaning and vacuum cleaning (listed in order of decreasing cost). Catch basins are of questionable value; while they can improve water quality, they are considered a costly MP method. The average cost of cleaning a catch basin using a vacuum is approximately $13/basin, while costs can go as high as $32/basin for hand cleaning (Oberts, 1982; Stanley Consultants, 1976).

SEWER FLUSHING

Description and Purpose

Sewer flushing is a method of cleaning out sediments by sending water through a sewer line. There are several ways to flush a sewer. An automatic internal flushing device has been developed in which an inflatable bag is used to stop the flow until enough water is collected upsteam of the station to create a wave capable of flushing the system. Once the correct volume is reached a pump deflates the bag creating a wave which travels down line cleaning a segment of the sewer. A second easily used method is to flush the system with any available supply of water during dry weather.

The purpose of flushing a sewer line is to reduce the "first flush" effects of a storm event, particularly in combined sewers. Flushing prevents the initial overflow of a large storm from picking up previously settled solids while in the sewer line.

Target Applications

Target pollutants are any sediments or solids that settle out of the water flow and may later be resuspended when the flow rate increases to overflow conditions. Sewer line flushing should be done during a dry period when the flow is low.

Effectiveness

Sewer flushing has been reported as removing 30-50 percent of solids from overflow events (Stanley Consultants, 1976). Higher efficiencies between 60-75 percent can be achieved by flushing daily with an automatic flushing unit (Athayde and Waldo, 1976). Effectiveness of sewer flushing on removal of solids is dependent on frequency of flushing, loading characteristics, type of flushing, and sewer line characteristics.

Planning Considerations

Sewer flushing is particularly beneficial in sewers with flat slopes that drain to a detention or treatment system. Since sediments are likely to remain suspended on flat slopes with lower flow velocities, periodic washing of this type of sewer is needed. Flushing is generally more effective on freshly deposited sediments, therefore a regular flushing schedule will keep sediments from permanently staying in a sewer line.

Design Considerations

Sewer flushing has been reported as being a more cost effective approach to controlling overflow quality than a collection system and treatment plant. Initial flushing unit costs are approximately $9400/unit. Annual O & M costs are approximately $850/unit (Lager et al., 1977). When using a flushing unit that produces a wave only a small segment will be cleaned by each unit. Wall friction and pipe irregularities act to dissipate the wave energy causing the wave to be effective for approximately 1,200 feet in a small or medium diameter sewer. To flush the complete sewer line a series of flushing units would have to be installed.

LITTER CONTROL

DESCRIPTION AND PURPOSE

Litter control can be achieved through source reduction and removal programs. The purpose of this MP is to keep waste materials from reaching the sewer system or other receiving waters while aesthetically improving an area's environment.

TARGET APPLICATIONS

Programs aimed at reducing litter can be targeted at controlling the litter source or at providing cleanup operations. The pollutants needing reduction include animal wastes, garbage, vegetation, oil and chemicals. These pollutants are highly degradable organics that decay rapidly causing high oxygen demands. Some wastes such as animal fecal matter may create health hazards by polluting waters with pathogenic organisms.

EFFECTIVENESS

The actual effectiveness of a leaf and litter program would depend on the extent of the program as well as public acceptance and participation. A California study found that 21 percent of all materials picked up by a street sweeper was litter (Lager et al., 1977). This demonstrates that litter does make a significant contribution to pollution. Estimates place the reductions of pollutants for a litter/leaf program between two and five percent (SEWRPC, 1980).

PLANNING CONSIDERATIONS

In cases where a city already practices a litter control program, a management plan could increase the application and further reduce any litter problem. There are two categories of litter control programs, source reduction and removal programs. Source reduction includes pet wastes, litter containers, recycling programs, regulation and ordinance and public education.

- Pet wastes should be banned on impervious surfaces, and near streams and lakes. Administration and enforcement costs are expected to be funded by violation penalties and related revenues though some cities already have pet waste ordinances. Enforcement of controls should continue or be increased where they exist. Minneapolis has recently passed a strict ordinance requiring that dog owners carry clean up materials when walking their dogs on park property.
- Litter containers should be conveniently placed in public areas. These trash receptacles should be emptied frequently to prevent overflow.
- Recycling programs should be promoted. Newspapers, cans and bottles are likely to be thrown away if they can't be returned for cash.
- Regulations and ordinances should be effective and enforceable.

- Public educational programs are necessary to develop successful "control" programs. Many programs hinge on public acceptance and compliance. For example, a waste receptacle in every yard wouldn't decrease litter if people still throw trash on the ground. The purpose of public education is to produce public participation.

Removal programs include garbage and refuse collection, leaf collection, street cleaning, catch basin cleaning and cleaning of public areas.

- Garbage and refuse collection can reduce the amounts of these materials that turn up in sewers and waterways. Improved solid waste collection schedules should be developed when necessary.
- Leaf collection occurs on both the municipal and private level. In urban areas leaf collection practices are mostly dependent on homeowners. Education programs stressing the need for proper leaf disposal may aid in successfully implementing this MP. Municipal leaf collection for streets is usually done using a street sweeper. When possible, pickup timing and efficiency should be improved.
- Previous sections of this report contain the information on street cleaning and catch basing cleaning.
- Cleaning public areas such as parks and commerical zones is usually done for aesthetic reasons.

DESIGN CONSIDERATIONS

Previous metropolitan studies estimate the 1982 cost of a leaf/litter program for an urban subwatershed in the Metropolitan Area as varying between $10,000 and $35,000. Other programs such as anti-litter and pet waste ordinances are to be financed through fines obtained in enforcing the laws (Oberts, 1982).

CHEMICAL APPLICATIONS

Application rates of chemicals such as deicing materials and fertilizers and pesticides can be reduced to improve water quality. The reduced use of toxic chemicals should reduce the amounts of these materials that pollute the surface water.

DEICING MATERIALS

Description and Purpose

Chemicals used to clear ice from the roads can be applied at reduced rates. Salt, the most commonly used chemical, leads to increases in the sodium and chloride content of surface and subsurface waters. Reduction in salt application should improve water quality. Two methods are recommended application rate reduction and substitution with other materials or mixes.

Target Applications

The target pollutants are Cl, Na and suspended solids. Reductions in salt use will reduce both Cl and Na levels. Frugal use of sand will reduce suspended solids levels.

Effectiveness

Increased chloride loads of 40 to 50 percent were experienced in Milwaukee during winter months (Stanley Consultants, 1976); similar increases were seen in 1980 for the Metropolitan Area (Payne et al., 1982). While the actual impact of this MP is not known it is hypothesized that most of the winter chloride increase is accounted for by deicing materials. Therefore a reduction in chloride application to roads should decrease chloride concentration in the water.

Planning Consideration

There are several methods available for reducing salt applications, such as the reduction of over application. Equipment should have calibrated application rates. Improvements in spreading and metering can be made with both the equipment and the operators. The need for deicing materials should be monitored carefully; materials should be applied at a rate appropriate for weather conditions to provide the minimumly acceptable service level.

Service levels may be developed for different roads. Low traffic roads and straight flat areas may need little or no deicing applications. Critical areas such as intersections and hills or major roads will need higher levels of service. An emphasis on plowing rather then salting, or a combined plowing and salting program should be used when possible.

Chemicals used for deicing should be properly stored and covered. Guidelines for propoer storage can be obtained from state transportation departments.

Public education will provide a realistic public understanding of road conditions and the cost of perfect service. Knowing indirect costs as well as direct costs may help gain acceptance of reduced service levels.

Design Considerations

Effective management of deicing practices can lessen receiving water impacts associated with chlorides, sodium and suspended solids, often without a substantial increase in costs.

Often indirect costs for deicing are not included in the cost analysis. For example, salt can inhibit the overturning of lakes because it changes the density characteristics of water where allowed to reach high concentration levels. Also, a U.S. EPA reference totaled direct and indirect cost and concluded that the direct cost of salt purchasing was only seven percent while corrosion damage made up 67 percent of the total cost (Lager et al., 1977). The actual cost of using salt as a deicing agent is much more expensive than it initially appears to be. Therefore reducing salt use has benefits not easily computed into monetary values. The following list outlines the disadvantages and advantages of reducing salt use on roads or substituting sand as a deicing material:

	Advantage	Disadvantage
Reduction of salt used	o Save on cost of salt. o Reduce contamination of water supplies both groundwater and surface water. o Reduce impacts on health (i.e., Na and Cl). o Reduce damage to vegetation. o Reduce damage to highway structures. o Reduce corrosion damage damage to both automobile and pavement. o Reduce roadside soil deterioration. o Reduce liklihood of inhibiting lake turnover.	o Decreased level of service, slower transportation movement. o Safety decreases stopping distances (Fitzpatrick et al., 1977; icy pavement 478 feet; sanded pavement 183 feet; salted pavement 66 feet.
Use of sand or or decreased salt/sand ratio	o Sand cheaper than salt 1975 costs (Oberts, 1980: sand $2/ton; salt $19/ton. o Reduction of salt use benefits (see above).	o Less effective at combatting poor road conditions. o Increase suspended solid load. o Sand clogs catch basins and sewers. o Higher labor costs.
Chemical additives	o Allows reduction of Na and Cl. o Accelerates action of salt. o Reduces clumping of Na Cl.	o Adds different chemicals to water.

PESTICIDES AND FERTILIZERS

Description and Purpose

The application rate of pesticides and fertilizers can be reduced to improve water quality. The purpose is to decrease the amount of these chemicals available to be washed into the waterways and degrade water quality.

Target Pollutants

The target pollutants are the pesticides and fertilizers. The application rate of these chemicals should closely match the need. Excess applications and use in or near surface water drainageways should be eliminated, and when practical alternative chemicals considered. Less toxic substances may be substituted with no loss in pest control or nutrient enhancement.

Effectiveness

The effectiveness of this MP would depend on how much reduction was achieved. One study (SEWRPC, 1980) estimated a 0-3 percent reduction of released pollutants, but such reductions are extremely hard to quantify

Planning Considerations

Municipal agencies and homeowners represent the urban users of fertilizers and pesticides. Municipal agencies spray trees, control weeds and fertilize parks and parkways. Homeowners use pesticides and fertilizers on their lawns and gardens. The best way to reduce chemical use is to implement awareness or control programs such as public education, municipal ordinances and professional licensing. Public education could be used to increase public awareness of potential hazards to receiving waters and provide instruction on proper use to avoid excess application. Ordinances could specify conditions under which chemicals can be applied and place limits on the types used. A professional licensing system could be used to ensure all handlers and users of fertilizers and pesticides were competent.

Design Considerations

Initial costs would be part of an education or legislative program. O & M needs include the need to enforce laws about pesticide or fertilizer use and the need for a continuing education program.

CHEMICAL STORAGE PRACTICES

DESCRIPTION AND PURPOSE

Improvement of storage practices is needed to reduce chemical discharge from stockpiles into the aquatic environment. The purpose of improved storage practices is to reduce stockpile runoff and local contamination of surface water and groundwater.

TARGET POLLUTANTS

The target pollutant depends on the chemical involved. In the case of deicing materials, proper storage is needed to decrease Na and Cl pollution of both groundwater and surface water. Improved storage practices should be implemented when dealing with deicing materials, chemicals or oils, road materials, or material stored for industrial use.

EFFECTIVENESS

The effectiveness of improved storage practices has not been determined. It has been estimated that proper storage practices will reduce the release of pollutants five to 10 percent, but again such reductions are almost impossible to quantify (SEWRPC, 1980).

PLANNING CONSIDERATIONS

Several steps are suggested for optimal chemical storage such as site placement, storage weatherproofing, runoff control and regulation compliance.

Site Placement

Storage sites should be chosen by considering more than accessibility. Site areas should be on impervious pads with upland drainage directed away from the site; they should not be on aquifer recharge areas; and they should not be on areas subjected to concentrated runoff from slopes, ditches, etc.

Storage Weatherproofing

Stormwater running off or infiltrating through a stockpile will transport chemicals to the aquatic environment. Stockpiles should be covered with nonstructural plastic tarpaulin or structural bins, cribs or beehive protectors, and have an impervious surface at its base.

Runoff Control

Diversions may be placed around a storage site to prevent runoff from leaving the storage area. (For information see section on Diversions.) Runoff from a storage site should be sent to an acceptable outlet or storage facility.

Regulation Compliance

Laws exist forbidding public firms from leaving toxic chemicals in enclosed storage areas. However, the law is rarely enforced except when a complaint has been lodged. Suggestions to increase regulation compliance include an extensive public education program, and improved enforcement and penalties according to existing laws. Where regulations do not exist, such as the storage of deicing materials, voluntary compliance may be achieved through increased public awareness and state/county recommendations.

DESIGN CONSIDERATIONS

The costs of storage covers have been estimated as follows (Oberts, 1980).

Method	Cost
Tarpaulin coverage	$5-9/ton
Bin, crib, dome structure	$90-120/ton
Beehive structure	$9-11/ton

INFLOW/INFILTRATION

DESCRIPTION AND PURPOSE

Inflow or infiltration directly into a sewer system can have an impact on water quality. An MP to deal with the problem is to inspect for, and correct, contributing sources. Inflow usually occurs from sources such as roof drains, foundation, cellar and yard drains, depressed manhole covers and cross-connections. Infiltration sources include defective or disintegrating joints or pipes, manholes and improper connections.

TARGET APPLICATIONS

Illegal drain connections represent a major water inflow problem. They increase the frequency of overflow conditions by decreasing the sewer capacity available for stormwater runoff. Connections directly to sewers remove the opportunity for water to run over the surface, thus preventing chances for detention and infiltration.

EFFECTIVENESS

The effectiveness on water quality has not been determined, but benefits to controlling illegal drain connections have been reported. A Springfield, Illinois study determined that once downspouts were disconnected there were reductions in basement flooding, combined sewer overflows and wastewater treatment operation costs. Such benefits are particularly pertinent to those areas with combined sewers (Stanley Consultants, 1976).

PLANNING CONSIDERATIONS

Infiltration is a problem in the operation of sewer systems. Neither combined nor separate sanitary sewers are designed to cope with large quantities of infiltration flow. For existing sewer infiltration the correction options that are available include replacing the defective component, sealing the existing openings or building within the existing component.

DESIGN CONSIDERATIONS

The first step to curing an inflow/infiltration problem is to inspect for sources. Inspection costs can run $3-6 per building and $2-5 per foot of sewer (Lager et al., 1977). Inflow elimination costs can be estimated as follows:

Method	Cost
Leakage around manhole covers	$100-150
Holes in manhole covers	$200-250
Foundation drains	$600-2,400
Disconnect downspouts	$100-150
Cross connection	$200-1,000

ATMOSPHERIC FALLOUT

DESCRIPTION AND PURPOSE

Natural and human activities add materials to the air that will eventually settle out as fallout or precipitation. These particles become a source of water pollution. Reducing air particle loading and removal of settled particles should have some effect on reducing water degradation.

TARGET APPLICATIONS

Target pollutants are airborn particles such as nitrogen oxides (NOx), sulfur oxides (SOx), solids and metals. Reduction of particle sources could be achieved through attention to construction activities, to combustion of fossil fuels and to the wearing of urban surfaces. Collection of particles after deposition is also possible by cleaning urban surfaces. Both methods are aimed at containing and controlling particles before they enter a waterway.

EFFECTIVENESS

The effectiveness of airborn particle control on improving water quality is not known. The effects of various control practices on air quality are known and it can be assumed that a percentage of airborn particles will end up in the water. The effectiveness of various practices at dust reduction is estimated as follows (Stanley Consultants, 1976):

Method	Dust reduction
Construction controls	40-80 percent
Road dust controls	40-85 percent
Emission controls (automobile pollution control devices)	10-60 percent
Traffic controls (traffic flow, improve public transportation, vehicle restrictions)	3-25 percent

PLANNING CONSIDERATIONS

Construction sites are the primary source of dust in urban areas. Methods of control are discussed in the section on construction erosion. Urban surface cleaning uses methods such as street sweeping which limit addition of particles to the air as well as removing settled particles before they are washed into the waterways.

Emission control from the combustion of fossil fuels reduces air particle matter. Type of fuel burned, such as unleaded gas or low sulfur coal, affects the amount of particles discharged. Control measures are often mechanical systems such as catalytic converters and pollution control devices, and industrial measures such as fabric filters, scrubbers, and cyclones.

DESIGN CONSIDERATIONS

Some control equipment uses water to remove air pollutants. Unless this water is properly treated, particles change from nonpoint to point source pollution, but the effect on water quality remains the same.

Regulations require the compliance to a set of emission control standards. Enforcement is usually achieved through licensing requirements and policed by state agencies. Other sources, such as urban surfaces and construction sites are controlled by local programs.

EROSION CONTROL

SOIL SURFACE PREPARATION

Soil surface preparation methods are temporary measures used to protect the soil during the intermediate stages of development and the long-term preparation of the soil surface for future stabilization. Soil preparation includes topsoiling, surface grading and surface roughening.

TOPSOILING

Description and Purpose

Topsoiling involves removal and stockpiling of the upper layer of surface soil or the importing of soil for future spreading over exposed areas. The purpose of topsoiling is to provide a good quality soil surface to support the final vegetation for site stabilization.

Target Applications

Topsoiling will improve vegetative growth by providing a suitable soil. Topsoiling is applied when subsoils are considered to be inadequate for sustaining the desired vegetative growth. It is usually used on areas disturbed for land grading or construction purposes. Topsoiling should only be applied on flat surfaces or mild slopes.

Effectiveness

Topsoiling has no measurable effect on water quality. It does not reduce erosion by itself but has the long-term effect of improving vegetative growth which then decreases sediment loadings.

Planning Considerations

Most topsoils contain high concentrations of organic materials, nutrients, moisture and tend to have a friable consistency. Topsoil provides better support for vegetation, but disadvantages exist. Topsoiling may not be cost effective. Stripping, stockpiling and reapplying or, alternatively, importing topsoil and applying require time and money. Topsoiling may delay revegetation operations and increase soil surface exposure time. Topsoil may contain weed seeds that will compete with desired plant growth.

The best use of topsoiling depends on the cost of properly preparing the subsoil to sustain the desired vegetation vs. the cost of topsoiling. The quantity of topsoil available at the site and its condition are factors used to decide whether to save the existing topsoil or import topsoil from a different location. Topsoiling is best applied when future vegetation will be ornamental or high maintenance turf or when extensive preparation would be required because subsoils are poor, very shallow, acidic, or potentially toxic.

Design Considerations

Costs of applying topsoil have been estimated at $4,750/acre (Stanley Consultants, 1976). Total costs will depend heavily on labor wages.

Topsoiling considerations include locating the stockpile away from the immediate construction area, protecting stockpiles from erosion by temporary seeding or sediment control barriers and scheduling to allow ample time to spread soil before revegetating the surface.

Difficulties in use may occur when the topsoil and subsoils are made of contrasting materials. For example, the clayey topsoil over a sandy subsoil will not drain properly and sloughing may occur. Bonding by roughening the subsoil surface before topsoiling could be necessary. Improperly bonded soil will lead to uneven soil infiltration and difficulties in vegetation establishment. Other construction difficulties that will decrease topsoil effectiveness include applying frozen, muddy or excessively wet topsoil, increased compaction of topsoil, nonuniform spreading and surface irregularities.

SURFACE ROUGHENING

Description and Purpose

Surface roughening can be achieved using several different methods. Scarification is done by making horizontal depressions perpendicular to the slope with a tillage implement; other roughening techniques include tracking, grooving and furrowing (Figure 3). A rough soil surface can also be obtained by eliminating the fine grading of rough surfaces. The purpose is to reduce erosion by providing sediment traps, reducing runoff velocity, increasing infiltration and aiding in the establishment of vegetative seed cover.

Target Applications

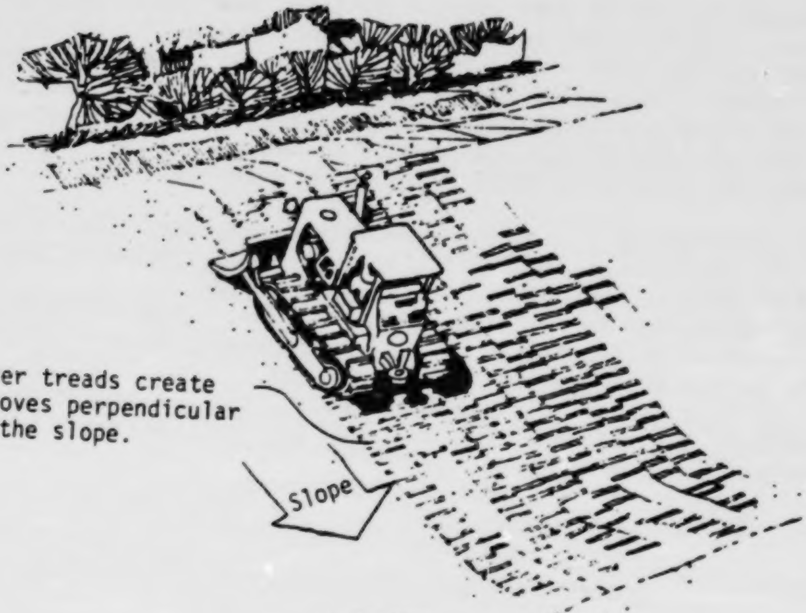
Surface roughening is used to reduce erosion and subsequent stream sediment loading. Roughening is applied to prepare the soil surface for seeding, and is particularly important for hydroseeding. Roughening is recommended for areas which have been graded but will not be stabilized for awhile.

Effectiveness

The effectiveness of surface roughening varies, with reports ranging from 85 percent erosion reduction to an increase in soil lost because of this method (Oberts, 1980). Roughening is considered effective at protecting seeds during germination by reducing gullying and providing cover. Scarification was found to be most effective on short slopes though it can be applied on steeper slopes along with grooving, furrowing and step grading. Tracking is only effective on mild noncritical slopes.

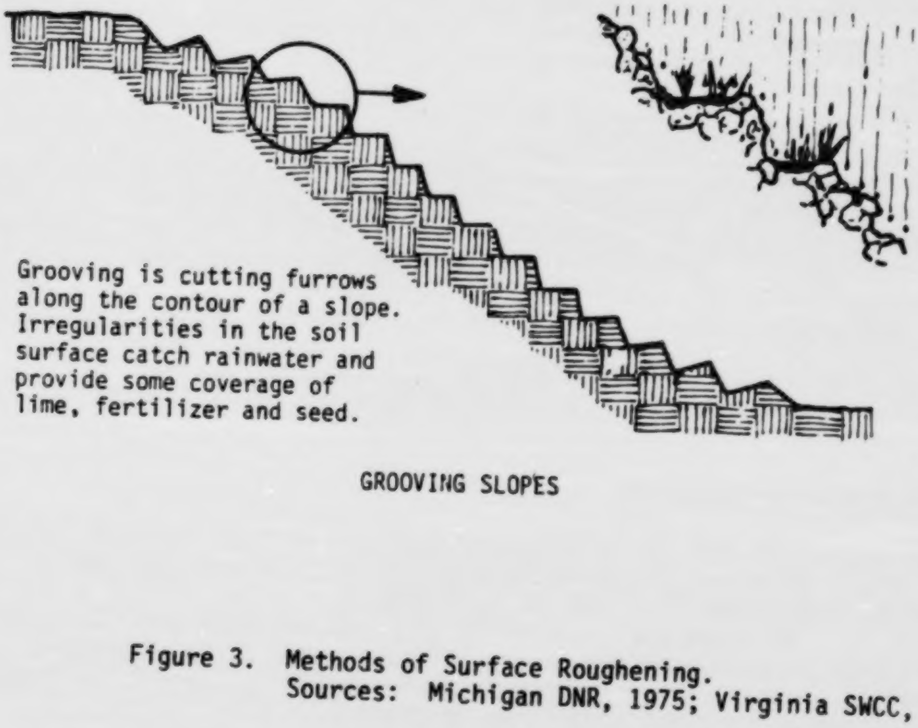
Planning Considerations

Smooth surfaces have increased erosion and runoff, reduced infiltration and cause difficulties in establishing vegetation. Rough soil surfaces provide some natural coverage for fertilizer and seed. It is particularly important with hydroseeding which spreads a slurry on top of the soil. Choice of roughening methods depends on slope and maintenance requirements. Steep slopes that do not need mowing can be step graded. Noncritical slopes that will be mowed should have shallow furrows created by discing, harrowing, racking or tilling.



Dozer treads create grooves perpendicular to the slope.

TRACKING



Grooving is cutting furrows along the contour of a slope. Irregularities in the soil surface catch rainwater and provide some coverage of lime, fertilizer and seed.

GROOVING SLOPES

Figure 3. Methods of Surface Roughening.
Sources: Michigan DNR, 1975; Virginia SWCC, 1980.

Design Considerations

Soil roughening can be done using almost any available construction or farm equipment. Specific design requirements on depression spacing and depth must be determined for each site. The slope steepness may affect the roughening method choice. Roughening on a slope will be limited by the criticalness of the slope. Some equipment cannot be operated on extremely steep slopes. Future use may also affect the roughening method choice. Any area that will be mowed must be relatively smooth without deep grooves, furrows or steps.

Various construction limitations are method specific. The following are just a few of the specific difficulties that may be encountered. Step grading is limited to soft soils that can be cut by a bulldozer. Step cuts should be proportioned according to the slope and soil type. Tracking with bulldozer treds is the least effective method of soil roughening. Severe surface compaction from the heavy machinery can increase runoff. Tracking recommendations include using it only on sandy soils (not clayey soils), minimizing the number of bulldozer passes, and running it up and down the hill to create horizontal depressions.

SURFACE GRADING

Description and Purpose

Land grading involves reshaping the surface to planned elevations and slopes. Grading requires a detailed engineering survey and layout to design the grading plan. The purpose of grading is to control soil erosion, to improve surface drainage, to landscape aesthetically and to provide a suitable site for buildings, streets or other land uses.

Target Application

This practice applies to sites where grading is needed to obtain planned elevations. Land grading is used for construction purposes such as providing a flat surface for construction, aesthetic purposes such as landscaping, or erosion control stabilization of a slope by reducing its gradient.

Effectiveness

Land grading provides along term erosion control benefit. Grading plans are designed to reduce future erosion problems but short-term effects are difficult to quantify.

Planning Considerations

Considerations for designing a grading plan include location, slope, alterations, original and final surface elevations, control and removal of runoff water, slope stabilization and soil erosion control. Grading is best used when held to a minimium and coordinated with natural site features such as natural drainage patterns and existing vegetation. Currently government controls and grading ordinances are in effect in many areas to prevent the creation of oversteep or critical slopes due to grading.

Design Considerations

When developing a grading plan, cut or fill slopes should be at a safe angle of repose. Flatter slopes are preferable since they are easier to maintain and result in less erosion. Surface runoff should be divered to prevent erosion damage to cut faces or fill slopes. Using frozen, soft or wet materials will create unstable fills. Construction difficulties can result from a high water table, which may threaten slope stability or building foundations. Fills that will support structures must be suitably compacted or slipping, erosion or soil saturation might occur.

VEGETATION

VEGETATIVE ESTABLISHMENT

Description and Purpose

This MP addresses the establishment of vegetation on disturbed areas. Vegetation can be applied in the form of temporary seeding, permanent seeding, hydroseeding, planting or sodding. The purpose of vegetating is to reduce erosion and sediment by stabilizing disturbed or vulnerable areas. Vegetation aids in reducing mud and dust generated at construction sites. Vegetation also enhances natural beauty and provides wildlife habitats when used in landscaping. An alternative to vegetating a complete area would be to plant buffer strips, or bands of vegetated soil which extend across water paths. Buffer strips are aimed at flow rate and sediment reduction and increased infiltration, not specifically at erosion control.

Target Applications

Vegetation is used to reduce delivery of sediments and associated nutrients to the waterways. It is applied in a situation where a soil surface is temporarily or permanently exposed to erosive elements such as wind, rain or runoff.

Effectiveness

Vegetative cover can effectively reduce water quality pollutants. The following are general reductions obtained by establishing vegetation (Oberts, 1981):

Pollutant	Percent Reduction
TSS	75-90
TN	50
TP	50

Planning Considerations

When planning vegetation use the site characteristics should be analyzed. Vegetation selection, site preparation, and seed application methods are chosen in accordance with site requirements. The adaptability of vegetation lends it to many alternative uses. Vegetation is used to directly protect streambanks and slopes from erosion. Buffer strips can be used around stream banks or construction sites to remove some of the sediment in the runoff. The use of vegetation does require commitments of undeveloped land as buffer zones, streambank corridors, open areas as well as labor to provide the required maintenance.

The process of selecting vegetation should center around site characteristics and requirements. Selection criteria include the type of vegetation; temporary, permanent, hydroseeding, planting or sodding. The appropriate species is chosen by comparing the physical situation; season, slope, soil type, shade, moisture and site use with species adaptions and limitations.

Surface water control measures are installed as needed and surface roughening, grading and topsoiling are performed to prepare the site for vegetation. Chemicals, lime and fertilizer are added at rates specified for the species and site characteristics. Rates are often determined after soil tests indicate lacking nutrients. Improper seedbed preparation can cause inadequate vegetation growth.

Seed application should follow either the local Soil Conservation Service recommendations or contracted specifications. Seeding considerations including seed application rate, use of mulches or erosion control mats are based on the criticalness of the sites erosion problem.

Design Considerations

Specific design considerations are dependent on the vegetative methods as well as the species. For planting instructions refer to MASWCD, 1973; Sheib et al., 1976; or contact the local Soil Conservation Service.

The following general cost comparison table contains average values for seeding:

Seeding Costs ($/Acre)*

Component	Seeding	Critical Seeding
Seedbed preparation	30	50
Seed	10-20	30-40
Equipment	10	200-500
Labor	30-50	160-720
Total	80-110	440-1,310

* Personal communication with the Minnesota SCS.

Variances due to seeding practices, seed type and labor costs should be expected. Seeding refers to seeding done with farm type equipment such as a grain drill. Critical seeding refers to seeding on a steep slope or critical area where hydroseeding or manual seeding is necessary.Vegetation is perhaps the easiest erosion control method available for development. It tends to be inexpensive and provides additional benefits in improving the environment.

TEMPORARY SEEDING

Description and Purpose

Temporary seeding is the establishment of annual grasses, annual legumes and small grains. Annual plants provide short term protection for areas exposed from one to 12 months.

Target Applications

Temporary seeding is intended to reduce erosion and sedimentation. Temporary cover is most useful for construction sites where short term exposure is likely to occur. Temporary seeding is applied on areas that have been stripped of vegetation but a delay in grading, permanent vegetation or construction has been scheduled. Typical application sites include cuts or fills, construction sites, soil stockpiles, dikes, dams, temporary road banks and sediment basin banks.

Effectiveness

Temporary seeding is very effective for short term exposure. Compared to leaving the soil bare seeding can reduce erosion 90-95 percent once a full stand is established (Oberts, 1981). Temporary seeding tends to be fast growing but higher erosion rates will still occur while vegetation is being established. To increase erosion reduction efficiency while seedlings are developing, mulches can be used.

Planning Characteristics

Planning suggestions listed under vegetation apply to temporary seeding. Temporary cover is best used to control sheet erosion. It may prevent costly maintenance operations on other erosion control systems that may fill with sediment. Temporary seeding is also useful for preserving temporary earthen sediment control structures such as dikes, diversions, dam banks and sediment basins.

Design Characteristics

Temporary vegetation can be established satisfactorily on subsoils without using mulch, though mulch is recommended for adverse soil conditions. Improper preparation and seed choice may cause inadequate growth, in which case reseeding is recommended. Other than inspection for inadequate growth there were no O & M costs. Recommended temporary seed for the Minnesota region include annual grass, legume and small grains such as annual ryegrass, perennial ryegrass and oats.

PERMANENT SEEDING

Description and Purpose

Permanent seeding with perennials, grasses or legumes provides long-term vegetative cover. Planting controls both wind and water erosion resulting in reduced waterway sediment loading. Permanent seeding stabilizes disturbed areas in an adaptable and environmentally attractive method.

Target Applications

Permanent seeding is suggested to stabilize any sediment producing area that will remain exposed for a year or more. Examples of exposed areas where long term vegetation may be useful are completed or operating construction sites, dams, dikes, mine spoil, waterways and channels.

Effectiveness

Effectiveness depends on the successful establishment of a full stand. Once vegetation is established a 95-99 percent erosion reduction occurs. Permanent, established grasses are found to provide the most effective erosion protection at approximately 99 percent (Oberts, 1981).

Planning Considerations

Recommended vegetation planning considerations apply for permanent seeding. The advantages of permanent vegetation over other control measures are the small initial establishment cost, low labor requirements and minimal O & M expenditures. A wide variety of grasses and legumes are available for different site specifications, shade levels, soil type, moisture content and season. Vegetation can be established in critical areas with relative ease.

Disadvantages are that erosion is not controlled before or during vegetation establishment. Failed areas must be reseeded and seasonal limitations exist on the optimal seeding date. It may be necessary to time climatic conditions and maintain water levels needed for germination.

Design Considerations

The following species are recommended for use in the Minnesota region:

Grasses	Legume	Native Grass
Bromegrass	Crownvetch	Big bluestem
Tall fescue	Birdsfood trefoil	Little bluestem
Orchard grass	Alfalfa	Indian grass
Reed canary grass	White clover	Switch grass
Blue grain		Sideoats grama
Creeping red fescue		
Redtop		

Recommended application rates vary by species, specific information can be obtained from the local Soil Conservation Service. Seed quality should be maintained and seed should meet all requirements of the Minnesota State Seed Law. Legume seeds should be innoculated with the required innoculant and used within the specified time period.

O & M requirements vary depending on the grass chosen and site use. Vegetation is not considered fully established until it has existed for one year. Until that time inspection of cover should be done periodically and reseeding should occur immediately if cover is found to be inadequate. If vegetation exists but is not properly preventing erosion the area can be overseeded and fertilized. Sites where 40 percent or more of the vegetative cover has failed should be reevaluated. Plant species, fertilizer and lime quantities may be altered and the site regraded and seeded.

After vegetation establishment, O & M costs depend on the maintenance level desired. High maintenance grasses used for lawns require regular mowing and fertilizing while low maintenance combinations are available that require little or no mowing and fertilization.

HYDROSEEDING

Description and Purpose

Hydroseeding is the application of seed and fertilizer in a water slurry. This mixture is sprayed on the slope as a method of vegetation.

Target Applications

Hydroseeding is a method of vegetating, used to reduce the delivery for erosion control of sediments and associated nutrients to the waterways. Hydroseeding is often applied for erosion control to slopes too steep for regular seeding equipment. Other critical areas are prime targets for this method of vegetation.

Effectiveness

Germination rates tend to be lower for hydroseeding than other seeding methods. Higher sowing rates are sometimes employed to retain the same effectiveness. Mulching is often suggested for critical areas. This may improve successful germination and will provide erosion control while plants are becoming established.

Planning Considerations

Hydroseeding provides uniform application of seed, fertilizer and mulch. All three components can be applied in one step saving equipment operation costs and labor costs. The slurry can be applied without damaging a critical slope with vehicle or pedestrian traffic.

Hydroseeding can not be used unless a firm surface adjacent to the site and a readily available water supply exist. Other disadvantages are the large capital investment and the fact that hydroseeding does not place seeds in the soil but spreads them on top of the surface reducing successful germination percentages.

Design Considerations

This method has a minimal labor requirement resulting in low labor costs, but high equipment costs offset the savings. Initial costs range from $3,000 to $7,000 for a 250 gallon unit to as much as $160,000 for a 5,000 gallon self powered unit (White and Franks, 1978). Application costs are:

Seed and fertilizer	$270/acre
Labor and equipment	$510-910/acre
Total	$780-1,180/acre

Surface roughing is recommended to provide coverage of lime fertilizer and seed. Application of lime should be done separately since lime acts as an abrasive within the hydroseeding equipment.

PLANTING

Definition and Purpose

This section addressed the planting of trees, shrubs, cuttings, vines or ground cover to stabilize an erosive area. Planting will reduce soil erosion, conserve moisture, provide wildlife habitat, filter air pollutants, decrease stormwater runoff and increase attractiveness by providing shade, privacy screening and wind or sound barriers.

Target Applications

Planting provides vegetative groundcover that reduces the transportation of sediments and associated nutrient. The following situations represent a few of the suggested applications for tree, shrub or ground cover planting.

- Planting to reduce erosion on steep or rocky slopes where mowing is difficult;
- Landscaping with ornamental plants to create an attractive environment;
- Using ground cover in shady areas or poor soils where grasses do not grow well;
- Establishing woody plants where needed for soil conservation, wildlife habitat or restocking existing woodlands; and
- Retaining plants left on construction sites to reduce erosion.

Effectiveness

Planting reduces the erosion of sediments. Planting grass, clover or ground cover reduces soil loss experienced with seeding during germination. Planting is also effective when used on areas that are difficult to seed. Trees, shrubs and ground cover are perhaps the most effective component used in landscaping.

Planning Considerations

The choice of plants and their placement is dependent on species, plant function and environmental limitations. The following paragraphs describe the general categories of plants available for erosion control. Additional information can be found in the sections on grass and seeding.

Trees--Considerations for the choice of tree species are hardiness, mature height and spread, growth rate, cleanliness, moisture and fertilizer needs, ornamental effects and evergreen versus deciduous. The desired function of the tree should be considered when choosing a species. Different functions include shade, appearance, wildlife habitat, privacy, noise and wind screening. For placing trees the desired impacts should be considered. For instance, tree groups are more effective at reducing erosion though single trees are considered to have more functional aesthetic values. Trees should be chosen for their ability to cope with a variety of adverse conditions. Environmental problems that a tree might be subjected to include insufficient water or light, high wind velocities, quantities of salt, snow, heat, or pollution from urban sources and root disturbances or topping by sewer and power utilities. Protecting existing trees during urbanization requires foresight. Keeping desirable trees greatly increases an area's value. Trees often take decades to mature, so saving existing trees will provide a valuable resource in a newly developed area.

Shrubs--The choice of shrubs is dependent on factors similar to those listed for trees. Shrubs provide an extra benefit in that they are close to the ground and tend to spread out, thus providing a more effective rainfall energy dissipation.

Ground Cover--As an erosion control method, ground cover is best used in areas where seeding will be unsuccessful. For example some vines can thrive in shaded areas where grasses cannot grow. The choice of ground cover species should be made weighing environmental limitations and species adaptability as described for trees.

Design Considerations

Planting specifications such as those published by the Soil Conservation Service should be followed. Topics that should be considered are plant quality, quantity, planting rate, time of planting, site preparation and method of planting.

Initial costs are for labor and the plants themselves. Plant costs vary depending on species, seedlings being cheaper than developed plants, but less likely to mature successfully. Costs may range from $0.10 for a seedling to several hundred dollars for a tree. Unskilled manual labor can be used to fulfill the labor requirements for planting (White and Franks, 1978).

O & M costs are low. Watering when soil becomes extremely dry may be necessary. Yearly trimming of dead materials will improve new growth, and the appearance of plants. Every one to five years mulch or fertilizer may be added to improve growth or aid in aesthetic appearance.

SODDING

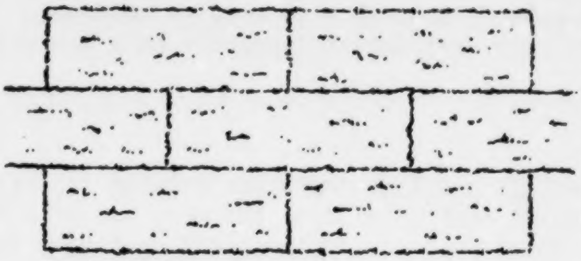
Description and Purpose

Sodding is the placement of turf made up of grass, root system and a cohesive layer of soil taken from another site. The purpose of sod is to establish immediate soil surface stabilization for the prevention of erosion and reduction of dust and mud.

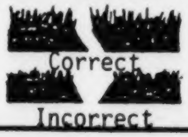
Target Applications

Sod can be used to reduce suspended solids by providing erosion control or filtration. It is applied to areas needing instant vegetative cover to prevent critical erosion. Sod is also used in areas where other vegetating methods are impractical. Suggested applications include areas where vegetative establishment might be difficult, such as gullied areas, slopes, drainage ways or swales carrying intermittent concentrated overland flows, waterways, dam or sediment basin banks, areas around drop inlets and residential or commercial lawns requiring quick use or immediate aesthetic improvement (Figure 4).

SODDING

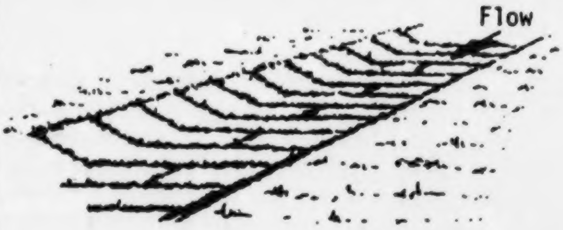


Lay sod in a staggered pattern. Butt the strips tightly against each other. Do not leave spaces and do not overlap. A sharpened mason's trowel is a handy tool for tucking down the ends and trimming pieces.



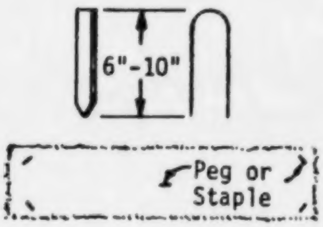
Butting - angled ends caused by the automatic sod cutter must be matched correctly.

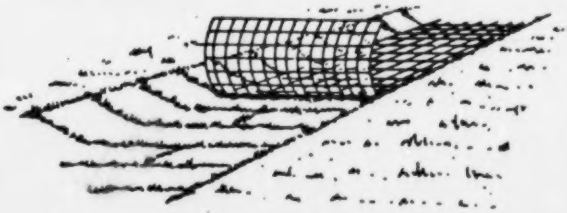
SODDED WATERWAYS



Lay sod across the direction of flow.

Use pegs or staples to fasten sod firmly - at the ends of strips and in the center, or every 3-4 feet if the strips are long. When ready to mow, drive pegs or staples flush with the ground.





In critical areas, secure sod with chicken wire or netting. Use staples.

Figure 4. Proper Sodding of Critical Areas.
Source: Virginia SWCC, 1980.

Effectiveness

Sodding is just as effective as a full stand of seeded grass at erosion reduction. Unlike seeding, sodding has the benefit of providing erosion control immediately after installation. As an erosion control device, sodding provides up to 99 percent erosion reduction. Sodding also retains sediments; up to 66 percent suspended solids have been reported as trapped from a low velocity sheet flow (Oberts, 1981).

Planning Considerations

When sod is properly installed, it provides immediate erosion control. The benefits of sodding include quick control of dust and mud, use of a green surface, freedom from weeds, elimination of a lengthy planting period and reduction of vegetation failures.

Design Considerations

The steps for successful sodding can be found in Sheib et al., 1976; Virginia SWCC, 1980; or a variety of other local sources. The steps include site preparation, sod choice, sod placement, stabilization and maintenance. Sod maintenance depends on the area´s use. Recommendations are to fertilize annually and control weed growth with chemical applications. High maintenance sod such as lawns require mowing weekly or biweekly, while low maintenance sod can be mowed as little as once a year.

Difficulties in sodding may occur in critical areas. Slopes or waterways require tacking to stabilize the sod until the root system anchors the grass. Stakes, chicken wire, jutemesh or wire stables are few of the materials that can be used (see Figure 4). A runoff diversion may be implemented to allow sod time to adapt before it is exposed to heavy runoff. Extremely dry weather may temporarily damage the grass, though the brown grass will recover when the drought ends. To maintain green grass, water must be applied during dry weather.

Sodding is generally easy to place and maintain. Damage areas do not pose much of a problem since repairs are easily made. Sods suggested for the Minnesota region include Kentucky bluegrass, creeping red fescue or reed canary grass. Installing sod rather than seed is initially more costly, but sod performs better than seed and is less difficult to establish. The sod weight and bulk are partially responsible for the high application costs. Laying sod is labor intensive, though unskilled manual labor can be used. Sodding costs are estimated between $7,500-9,600/acre (Virginia SWCC, 1980).

MULCHING

DESCRIPTION AND PURPOSE

Mulching is the application of organic or inorganic materials to the soil surface. Mulching reduces erosion by protecting the soil surface from rain drop impact and reducing velocity of overland flow. It aids in establishing vegetative growth by conserving moisture, providing insulation from extreme temperatures and controlling weeds. Methods used to anchor mulches include chemical tacking agents, disking, punching and tucking, and erosion control mats.

There are several types of mulch: hydromulch, straw mulch, woodchips, crushed gravel, chemical mulches and others.

- Hydromulching is the application of woodfiber to the soil in a water slurry. It can be used with or without hydroseeding or a tacking agent.
- Straw mulch is applied with a blower or manually to protect bare or seeded soil surfaces. This mulch requires matting or tacking to hold it in place.
- Woodchips are used on construction sites or as a mulch around plants. Trees on the construction site may provide an inexpensive source of woodchips.
- Crushed gravel mulches are often used on low traffic areas to protect surfaces from vehicular travel; see construction erosion control section. This mulch is also used as an ornamental mulch around plants.
- Chemical soil stabilizer can be applied as a mulch or as a tacking agent. A variety of chemical mulches are available, such as asphalt, terra tack, aerospray 52 and Petroset SB. Most of these chemicals are applied by mixing with water and spraying the soil surface.
- Other mulches can be developed from a suitable common material using local materials may reduce mulch costs; examples include corn stalks, barkchips or shredded bark.

TARGET APPLICATIONS

The target pollutants are sediment and associated nutrients. Mulching controls pollutants at the source by reducing erosion. Applications are suggested immediately after temporary or permanent seeding. Mulching should be used when seeding is delayed because of seasonal weather fluctuations. Mulching should be used whenever conditions are unfavorable for establishing plant growth such as steep slopes or when runoff, traffic or temperature threaten seed germination. Mulch is also recommended as temporary erosion control for construction sites when seeding is not desired.

EFFECTIVENESS

The effectiveness of mulch is dependent on application rates, combination of mulch with tacking agents, site characteristics application method, and time lapse between surface exposure and application. The following values are initial reductions (Lynard et al., 1980):

Method	Approximate Percent Erosion Reduction	Approximate Percent Nutrient Reduction
Hay and straw with tacking	90-95	60-80
Hydromulch	70-90	50-70
Wood chip mulch	90-95	60-80
Gravel stone	70-90	50-70

Mulches appear to become less effective with age. Reductions of effectiveness range 40-90 percent for the first two years. After two years, effectiveness can be as low as 0 to 10 percent.

PLANNING CONSIDERATIONS

Erosion control is best achieved by using a combination of MPs. Mulching is recommended for use with erosion control matting and seeding. An erosion control plan should consider the effectiveness of combining MPs. An example would be to use a berm to divert water flow from a steep cut while mulch is applied to protect the slope surface from rain impact and runoff.

DESIGN CONSIDERATIONS

Design considerations depend on which type of mulch is being considered. Hydromulching has several disadvantages: high capital cost, access requirements and water supply requirements. The high capital costs of equipment makes hydromulching expensive unless hydroseeding is intended as the vegetative method. Lack of maneuverability makes it difficult to get the equipment to a job site. A paved or firm surface is required near the application site, thus limiting the areas where hydromulching can be applied. Hydromulching requires water to form the slurry applied to the soil surface. Without a large available water supply close to the site hydromulching cannot be applied.

Hydromulching has many advantages. Labor costs are low since this method is mechanically intensive, that is, the machine can apply the slurry faster than any other application method. Hydromulching is also a rapid stabilization method and it provides needed moisture for seed germination.

Woodfiber is the material most frequently used to hydromulch. Other materials can be substituted, but woodfiber is considered to be the superior choice. Wood fiber forms a strong flexible mat that protects and holds seeds in place. Woodfiber cushions seeds against damage from the hydropump. Nontoxic dye which fades when exposed to light can be used to indicate where more mulch is needed. Generally hydromulching provides a uniform mulch distribution. If access is available to steep slopes hydromulching can be applied without subjecting the slope to pedestrian or equipment movement.

If hydroseeding is going to be used with hydromulching, the initial cost is defrayed since the same equipment is used. Estimates are that adding mulch to seeding and fertilization increases application costs only 10 percent. The ability to fertilize, seed and mulch at the same time reduces overall costs. Studies on hydromulches found tacking agents unnecessary and chemical binders did not seem to increase the effectiveness of woodfiber. The rate at which mulch is applied is important for effective protection. Manufacturers suggested rates should be followed, though critical areas or severe slopes (2:1 or greater) may require a doubled application rate.

Straw mulching is the most common mulch used. Straw mulch can be blown or manually placed. Manual labor tends to be more expensive than blowing, but blowing has several limiting conditions. Though blowing equipment is light weight compared to hydromulch equipment, it cannot be used where access is restricted. Blowing will only be effective if the area is within 20-30 yards of an access road or surface. Manual labor can be used to augment blowing in places inaccessible to the blowing equipment, but unless an inexpensive labor force exists, manual labor will be costly.

Straw mulch must be reasonably free of weeds or plant seeds and mold, or competition with the intended seeds will occur. The use of spring or early summer straw may reduce unwanted seed quantities. Straw is prone to blowing, therefore application during windy weather is not advised. Immediate tacking is necessary to hold straw in place. Tacking methods include punching mulch into the soil with a weighted disk. Unchopped hay or straw works best. Straw can be sprayed with chemical binders such as aspalt emulsion. Paper matting, plastic mesh or jute netting can be placed over mulch to secure it. Clean up will be required to collect straw blown around before tacking.

Woodchips can be used on areas that will not be closely mowed. They are also useful around ornamental plants, and are often used in landscape plantings. Wood chips decompose slowly, but the decomposition may create a nutrient deficiency in the plants if nitrogen is not added. As a construction site mulch, woodchips can be very inexpensive if obtained by chipping the trees cleared from the site. Woodchips have the benefit of requiring no tacking.

Gravel or crushed stone is excellent for mulch on short slopes around wood, around ornamental plants or on areas subjected to foot traffic. They are often used in landscaping. Crushed gravel is useful during construction and is used in swales, temporary berms or on temporary vehicle paths. Gravel tends to trap only large particles. This mulch should not be applied if vegetation will be desired in the future since removal of the stone will be necessary.

Chemical soil stabilizers are applied by spraying. As a mulch, chemicals do not provide the insulation and moisture retention that organic mulches give. Generally chemical mulches are more expensive than organic mulches and less stable. (Chemical mulches decompose in two to three months.) Chemical mulches are difficult to use. For example, the application rate of asphalt emulsion is critical, too much and seedlings cannot penetrate, too little and erosion occurs. Asphalt emulsion also requires special equipment to apply.

Application costs are variable. The mulch costs depend on availablity, shipping costs and quantites purchased. Buying large volumes of mulch will be cheaper than purchasing small amounts of this bulk product. Any mulch bought from local sources will be inexpensive, for instance woodchips from site removed trees or corn stalks from a nearby agricultural area.

The application rate will change costs the amount of labor and materials varies. Labor is one of the hardest costs to estimate. When wages can vary from $4 to $12/hour, labor costs will swing dramatically. The size of the area being mulched affects the unit/acre cost since larger areas will spread out the initial cost of getting the workers and equipment to the site.

The following costs may not reflect the actual cost of a specific site, however, these costs demonstrate the relative differences between types of mulching (Lynard et al., 1980; White and Franks, 1978):

Method	Mulch	Total Materials*	Labor and Equipment	Total
	Mulching Costs ($/acre)*			
Hydromulching				
- Woodfiber at 1,390 lb/ac	200	470	510	980
- Woodfiber at 2,490 lb/ac	340	610	650	1260
- Woodfiber at 4,970 lb/ac	680	950	910	1860
Straw mulching				
- Straw w/o tacking	140-220	400-530	650-1520	1050-2050
Woodchips	---	1000	130	1130
Chemical soil stabilizer	---	530	270	800
Crushed grave, stone mulches	---	830	240	1070

* Materials include seed, fertilizer and mulch.

In addition to mulching costs, there are costs associated with tacking down the mulch. The following tackifier costs reflect these additional costs when used with a straw mulch:

Estimated Tackifier Cost Applied Over Straw Mulch ($/acre)

Method	Materials	Labor and Equipment	Total
Chemicals	390-470	160-290	550-760
Asphalt emulsion	590	490	1,080
Woodfiber only	100	400	500

O & M costs are minimal; periodic inspections should be scheduled, and immediate inspection after a severe storm should be made to insure that no damage to the tacking system or mulch has occurred. Any damage should be repaired immediately before erosion starts.

EROSION CONTROL MATS

DESCRIPTION AND PURPOSE

An erosion control mat is a flexible net or blanket made from a variety of different materials. These mats prevent erosion by providing protection from erosive forces, raindrop impact, runoff and wind. Erosion control mats are used as temporary protection for soils, before or after seeding and fertilizing occur, until vegetation is established. Mats provide many of the same benefits as mulches, and when used with mulches they act as a tacking agent. Mats are also used on drainageways with slow flow velocities to reduce stream erosion. The following descriptions are of the most commonly used erosion control mats:

- Excelsior Blanket - This mat is made of curled wood excelsior bound together on the top side with a biodegradable paper or plastic mesh.
- Jute Mesh - Jute mesh is a uniformly coarse open mesh woven of heavy jute twine.
- Plastic Netting - This is a mesh of extruded biodegradable plastic strands formed into a clothlike material. Plastic netting must be used with mulches to provide any useful protection.
- Paper Fabric - This matting is made of thin paper strips interwoven with a synthetic yarn mesh.
- Fiberglass Roving - Molten glass is formed into fiber strands. These fibers are applied in an even continuous blanket using an air compressor fitted with a nozzle. A tacking agent, such as asphalt, is sprayed over the fibers to bind the strands together and adhere the blanket to the ground.

TARGET APPLICATIONS

The purpose of erosion control mats is to reduce sediment loading by reducing soil erosion. Mats are used on slopes or waterways to prevent erosion. On sloping surfaces mats are applied as a substitute for mulch. They provide the same benefits and can be secured to the soil surface more efficiently then mulches. When used in addition to mulches, mats act to tack down and secure mulch materials like straw. Used in a waterway, mats take the place of sod or mulch and reduce erosion during low velocity flows.

EFFECTIVENESS

Matting generally provides a very effective control against erosion. The following values are initial reduction of sediment loss by using an erosion control mat on a slope surface (Lynard et al., 1980):

Method	Sediment Loss Reduction	Nutrient Loss Reduction
Excelsior mat	50-90	30-70
Jute mesh	70-90	50-70
Plastic netting	Used alone no erosion control.	
Paper fabric	Used alone negligable erosion control.	
Fiberglass roving	90-95	60-80
Drainage channel matting, jute matting or fiberglass roving	50-90	30-70

Matting effectiveness was found to decrease with age. Aging from the initial placement to two years reduces erosion control 20 to 60 percent. Effectiveness after two years will range 0 to 10 percent. Most mats are biodegradable so that mat deterioration accounts for much of the effectiveness loss over time. Improper installation will also decrease net effectiveness. For example, a jute mat without continuous contact with the soil surface will allow erosion to occur under the mat.

PLANNING CONSIDERATIONS

Each type of mat has a different optimal use. Excelsior blankets provide the best coverage and adherence to the soil, and can be used when slope preparation is difficult. They are usually applied on a sloping surface without mulch.

Jute mesh gives good coverage and adherence to soil surfaces. Jute mesh can be effectively used in drainageways as well as on slope surfaces. This matting is applied with or without mulch.

Plastic netting is used to apply a straw mulch when a straw blower is not available and manual labor is inexpensive. Plastic netting provides no erosion protection by itself but works well as a straw tacking agent. It is applied on slope surfaces with mulch.

Paper fabric is very effective at retaining soil moisture even on very dry, exposed slopes. Paper fabric is used on slope surfaces with or without mulch.

Fiberglass roving provides very effective levels of erosion control and is relatively inexpensive compared to other matting costs. Fiberglass roving can be effectively applied in drainageways as well as slope surfaces without mulch.

DESIGN CONSIDERATIONS

The choice of an erosion control mat is dependent on how the site requirements compare to the mat application limitations. The following design limitations are listed by mat type. For specific application methods, manufacturer's recommendations should be followed.

o Excelsior blankets should be stapled at recommended intervals to prevent flows from occurring under the mat. Excelsior blankets are among the easiest to apply; it requires no extensive slope preparation since excelsior blankets form around slope irregularities. They also do not need to be anchored by burying the material at the top and bottom of the slope. Excelsior blankets can take up to 40 percent more time to install. Two factors are considered to account for these increased labor costs; the excelsior rolls come in smaller widths than other mattings and require more trips up the slope. Second, excelsior blankets are heavier. Excelsior blankets are not recommended for slopes greater than 1.5:1.

- Jute mesh must be installed on a smooth loose soil surface. All rocks and plant clumps should be removed. The mat edges should be anchored at the top and bottom of the slope. The mat should be stapled at recommended intervals. The edges should be overlapped at least 10 centimeters. Matting should be applied loosely since tension could allow gapping that reduces contact between mat and soil surface. The weight of jute mesh may require more effort to spread; but once on the slope, it is easy to work with because wind has less of a disturbing effect. Once down, it is easy to work with and move around on. Jute mesh tensile strength and weight allow it to be more resistent to water flow and erosion.

  Optional installation practices include rolling after placement to improve surface-mesh contact. For extra protection, check slots and anchor ditches can be dug periodically to stop any flow occuring under the matting.

- Plastic netting must have a smooth raked soil surface to allow close contact with the soil surface. Plastic netting is only used with mulches because it has no value by itself. After seeding and mulching, the netting is layed out with a 5-10 centimeter overlap of adjacent lengths and stapled at the recommended rate. Because of the lightweight and wide roll width, plastic net requires up to 40 percent less installation time. Plastic netting should not be used on slopes greater than 1.5:1.

- Paper fabric is applied to smooth raked soil surfaces after the slope has been properly prepared. Paper fabric should cover the ground loosely to allow full contact between the soil and fabric. Adjoining strips should overlap 10-15 centimeters and staples should be used at the recommended rate. A check slot should be used at the top and bottom of the hill and the fabric should be well stapled along all edges. Paper fabric does not require much manpower to roll out but can be difficult to apply if it is windy.

- Fiberglass roving is applied through a nozzle hooked to an air compressor. The compressed air spreads the strands evenly over the ground surface. A tackifier-like asphalt is applied to bind the strands together and to the soil surface. Fiberglass is not biodegradable and may have to be removed if revegetation fails. It is recommended that the fiberglass mat be buried at the top of the slope to decrease flow under the mat.

Erosion control mats are generally easy to install and require no maintenance. They are usually biodegradable and deteriorate with time, so they are not harmful to the environment and do not have to be removed. Being securely attached to the soil surface mats are more effective than mulches at reducing erosion. Manual labor requirements for applying mats make them more costly than mulches. Labors costs make up 50-80 percent of the total matting use costs.

The cost effectiveness of matting is dependent on labor costs. The following table itemizes the costs of erosion control mats (Lynard et al., 1980; White and Franks, 1978):

Erosion Control Matting Costs (Cost per Acre)

Method	Materials	Equipment	Labor	Total
Excelsior blankets	2,300	500	11,400	14,200
Jute mesh	3,500	400	8,200	12,100
Plastic net	900	300	5,200	6,400
Paper fabric	3,900	400	8,400	12,700
Fiberglass roving	2,500	200	2,600	5,300

STREAMBANK STABILIZATION

This section addresses structural or vegetative stabilization of streambanks to provide protection from erosion caused by moving water. The purpose of streambank stabilization is to prevent scouring of banks, control meandering, protect adjacent lands, maintain channel capacity and reduce sediment loading.

Streambank erosion is a natural occurrence, but escalates when urbanization increases stormwater runoff rates and volumes. Urbanization often includes realigning a stream course, which makes it straighter and shorter, but still spanning the same elevation drop. If a stream gradient is increased, additional streambank stabilization is needed to dissipate the excess energy created and prevent increased erosion or meandering.

VEGETATIVE MEASURES

Description and Purpose

Streambank vegetation stabilizes the soil, slows runoff, reduces gullying, dissipates erosive energy, filters sediment from overland runoff and increases aesthetic benefits and wildlife habitat.

Vegetative streambank protection measures include vegetation buffer zones (existing, seeding, planting, sodding), mulches, and erosion control mats.

Target Applications

By stabilizing the streambank, vegetative measures reduce the sediment which erodes into the channel. Vegetation measures can be applied along creek, stream and riverbanks whenever erosion occurs at a noncritical level. Planting downstream from urbanization will protect stream banks from increasing runoff volumes by reducing gullying as well as erosion. Vegetation use is often recommended in conjunction with a structural measure.

Effectiveness

The effectiveness of vegetation streambank stabilization at reducing erosion depends on the plant type, bank slope, and stream profile. Nearly 100 percent of all bank erosion sediment ends up in the surface water; therefore, any reduction in erosion will directly reduce the suspended solids in the stream water (Oberts, 1982). As indicated in the vegetation section, vegetation can improve water quality by reducing 75 to 90 percent of the TSS entering the waterway. Stabilization effects are low immediately after planting but increase as vegetation has a chance to become established.

Planning Considerations

When choosing a streambank erosion control method, the channel should be studied and stabilization planned considering soil type, surrounding land use and peak flows.

- Soil Type - Fine grains or silts are especially vulnerable to erosion. A combination of stabilization methods may be needed to cope with the varying soils along the stream.

- Surrounding Land Use - Protective measures must be compatible with adjacent land drainage requirements.

- Peak Flows - Vegetating measures should be able to withstand flow fluctuations.

The type of vegetation is important when providing streambank stabilization. Vegetation planted on streambanks should be able to withstand periodic submergence. The water level and typical fluctuation schedule should be used to determine the most useful vegetation for a particular area. Natural or adaptable vegetation is recommended for use in low and high water level areas. Streambank vegetation is choosen for its minimal maintenance requirements, erosion control capacity, durability, longevity, aesthetic benefit and value as wildlife habitat.

Plant types are broken up into the following categories: aquatic, reed, shrub and tree. All vegetation prevents erosion by binding the soil with its root system and when submerged, reduces water flow rate by creating friction.

- Aquatic plants are permanently submerged, but are difficult to establish. Aquatic plants often develop naturally when a reed bank is established.

- Reeds are submerged approximately half the year. Reeds can be seeded or planted in clumbs, slips, shoots or rolls. Reeds adapt well to use with mechanical stabilization such as riprap with reeds planted intermittently.

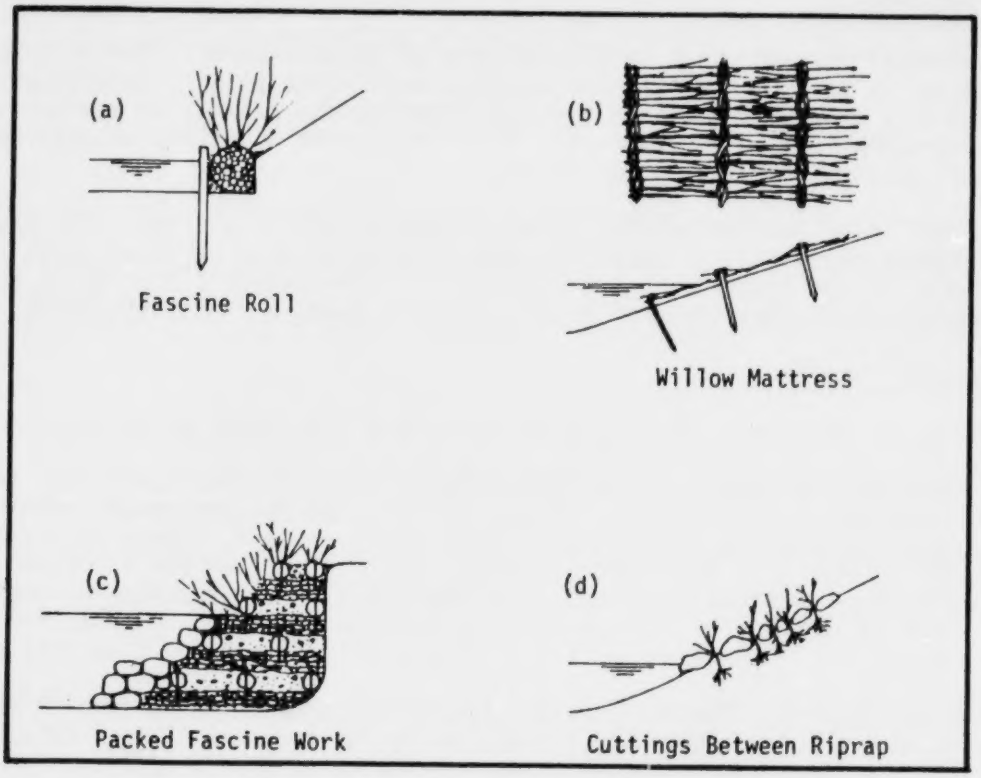
- Shrubs can be planted where periodic flooding occurs. Thick branches have the added benefit of reducing meandering. Erosion control mats, mulches and grass sodding are best implemented above the mean annual high water level. (For specifics, see the appropriate sections.)

- Trees are only planted where unusually high floodwaters flow. Trees provide the least satisfactory stabilization. Shade from trees may prevent growth of other ground cover.

Design Considerations

The cost of vegetation establishment is much lower than the cost of structural measures. Vegetation also has minimal O & M costs which consist of replanting and trimming growth as needed.

Construction difficulties occur when vegetating a steep or critically erosive area. Unless the bank is stable during the period of vegetation establishment, vegetation will fail. Combining vegetation and structural methods allow stabilization of critical areas using structural methods so that vegetation may become established. An example of vegetative structural combination might be a reed berm made of reeds planted between riprap or willow jetties (Figure 5). Placing a plant at the wrong water level zone will result in vegetative failure. Flow level fluctuations must be correctly determined since vegetation able to withstand periodic submergence will not necessarily survive constant flows.



(a) Fascine Roll

(b) Willow Mattress

(c) Packed Fascine Work

(d) Cuttings Between Riprap

Figure 5. Methods of Establishing Shrub Zone Vegetation.
Source: Seibert, 1968.

The ease with which vegetative measures are developed and implemented encourages the use of this erosion control method. Vegetating a streambank can be implemented as a community volunteer project. Vegetation is perhaps the method most compatible with natural stream characteristics. An alternative to introducing new vegetation is to maintain existing plants or supplement them to provide erosion control.

STRUCTURAL MEASURES

Description and Purpose

Constructing streambank stabilization to protect against the forces of moving water is often necessary in critical erosion areas. Structural streambank protection measures include grade stabilization structures, riprap, gabions, rock cribs, revetments, deflectors and reinforced concrete or masonary.

Target Applications

Structural measures reduce waterway sediment loading by controlling the source, bank erosion. Structural measures are applied to critical slopes, excessive erosion areas due to increased flows, disturbances caused by construction, or conditions where vegetation is not feasible.

Effectiveness

Structural measures have varying degrees of effectiveness. The principal purpose is to reduce erosion at a specific critical point. Structural methods correctly implemented can do this but often at the expense of another section of streambank; in which case, the method will have no effect on reducing total sediment loading to the water.

Not all stabilization methods reduce suspended solid loadings. For example, a revetment protecting a sharp bend reduces erosion of a critical point at the expense of the opposite bank or stream bed. The sediment loading is not reduced, just transferred to a less critical section of the stream bed.

Planning Considerations

General methods that can be implemented using structural protection include:

- Obstruction Removal - The first step in channel stabilization is the cleaning of fallen trees, stumps, debris, channel overgrowth, minor ledge outcroppings, and depositional sand or gravel bars. These obstructions may be constricting the channel causing accelerated flow and increased bank cutting. Obstructions that will interfer with construction or operation and maintenance of bank protection measures should be removed; for example, trees and brush which inhibit desirable bank vegetation should be cleared.
- Bank Sloping - The streambank slope should be reduced to provide stable conditions for vegetative protection or for the installation of structural bank protection, if needed. See section on surface grading.
- Fencing - Access to areas with streambank stabilization should be limited to maintain safety and ease of development. Fencing keeps unwanted traffic from streambanks and it will reduce the possibility of injury around structures and reduce damage to streambank vegetation.

Structures should be planned and designed by a qualified engineer or person with experience in this field. Construction of structural streambank stabilization measures should be planned and carried out in a manner that minimizes erosion and sedimentation.

Considerations that should be made in the planning and design stage include:

- When using a manufactured product, applications should be designed and installed according to manufacturer's specifications.
- Bottom scouring below bank protection is unacceptable. Structures should extend below the lowest anticipated scouring point, and bank protection should begin and end in a stabilized section of the stream. Both are necessary to prevent scouring that would undermine the structure and cause it to fail.
- Structural measures should be effective for controlling the designed flow, but must be able to withstand greater flows without serious damage.
- Structural or shaping measures must meet state law requirements and obtain the necessary permits from the appropriate local, state and federal agencies; such as the Department of Natural Resources and watershed districts.

A variety of structural measures are available to control streambank erosion, as follows:

- Grade stabilization structures reduce the flow velocity and, therefore, the erosive force on the banks. Typical structures used include check dams or spillways. (For details, see Energy Dissipation section.)

- Riprap consists of stone placed or dumped on the streambank. Stones come either uniform or graded in a well-mixed variety of sizes. Graded riprap tends to be easier to place and is more stable than uniform riprap. Installation specifications depend on the maximum flow height, thickness, rock size, and slope steepness. Riprap may require a gravel or plastic filter material at the interface between rock and soil. The filter blanket keeps soil from eroding through the riprap. Riprap should not be placed so that channel capacity is reduced. Riprap can be utilized for slope, channel and outlet stabilization.

- Gabions are wire mesh baskets made from a noncorrosive material containing rocks. Durable rock should be used, not sandstone or shale, which may disintegrate. Baskets should be constructed, filled and secured according to manufacturer's recommendations. Construction is from bottom to top of installation and smoothed foundation or filter material is applied as needed. Gabions are used as an alternative to riprap when large rocks are not available, or when more structural integrity is needed.

- Rock cribs are retaining structures built into the bank to protect against erosion. Cribs can be constructed from logs, concrete or steel bins and are filled with durable rocks that are large enough not to slip through the crib wall. Top rocks must be extra large to prevent removal. Cribbing is best used when built on the outside bank of stream bends for the protection of critical banks.

- Revetments are structures built on or parallel to the streambank to prevent scouring. Revetments can be made from masonry, reinforced concrete, sheet piling or gabions. The foundation must have a stable bottom elevation and be protected from structural undercutting. A drainage system should be installed to relieve seepage pressures from the bank face. Revetments are commonly used on sharp bends or with stream channel constructions (culverts, bridges, grade control structures).

- Deflectors are structural barriers which project into the stream diverting flow away from eroding streambank sections (Figure 6). Reflectors or jetties can be made from posts, piling, fencing, rock or brush. Deflectors may create relatively still water where sediments may precipitate out. Sediment build-up against a bank further aids in stabilization. Deflectors can encourage bed scouring instead of lateral cutting which may increase channel capacity. Difficulties may occur when deflectors restrict channel capacity and the stream compensates by scouring the opposite bank. Deflectors are best used on critical bends where the opposite bank is stable.

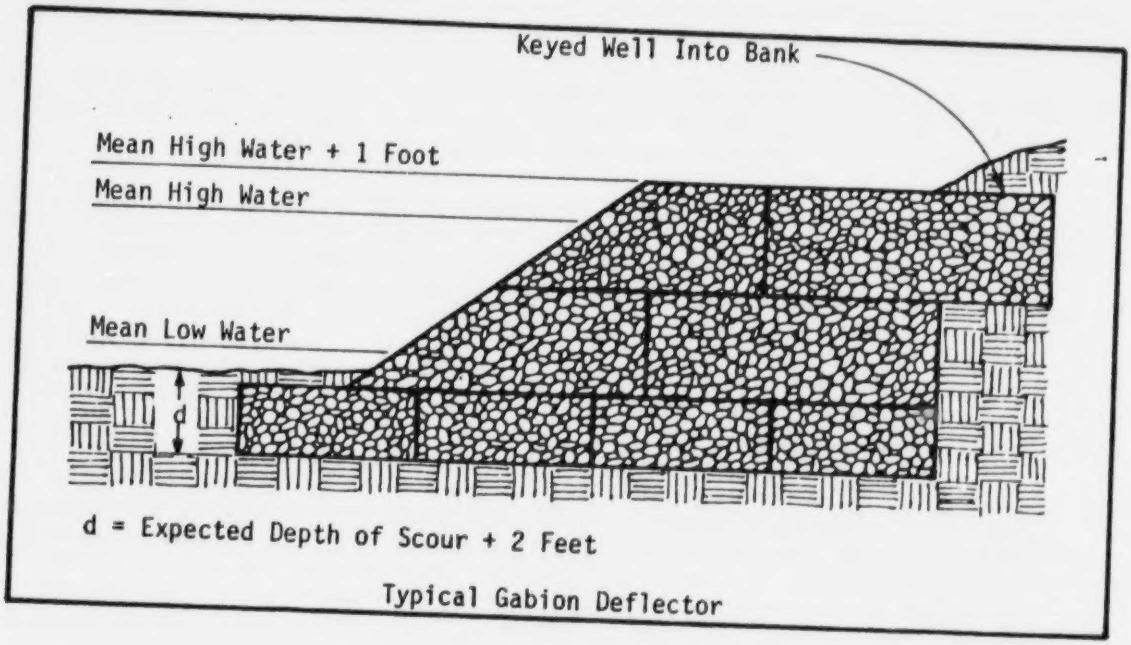


Figure 6. Example of a Structural Deflector.
Source: Virginia SWCC, 1980.

Design Considerations

Structural stabilization method costs are high. A large portion of the work is performed by unskilled labor. The cost is dependent on amount and cost of materials and on local wages, as follows (Stanley Consultants, 1976; Virginia SWCC, 1980):

Material	Material Costs
Riprap	\$45-90/yd.^{3}
Gabion	55-105/yd.^{3}
Deflectors	
Timber pilings	30-60/ft.
Gabion or rock	60-85/yd.^{3}
Log cribbing	60-85/yd.^{3}

Operating and maintenance represents a fairly costly procedure. The structure should be maintained in original condition, with repairs for storm damages made immediately. Operating and maintenance costs will increase as the structure ages. Replacement of structures costs from one-half to two times the original cost due to costs of removing the old structure.

Difficulties in construction depend on the type of structure used. Materials must be durable, concrete should hold up in freeze/thaw and rocks should not disintegrate. Rocks that are too small will not remain where placed. Rough handling of liners will rip or displace them.

Structural methods require comprehensive planning to determine the full impacts of stabilizing one section of bank. Miscalculations can increase scouring in other areas, increase flooding or prove ineffective for reducing erosion on the critical bank.

DRAINAGEWAY PROTECTION

Stormwater surface drainageways consist of man-made or natural channels that convey stormwater. Stormwater drainage does not refer to natural channels with continous flow, but to channels that conduct periodic concentrated overland flow without erosion or flooding damage. The increase of impermeable surfaces in urbanizing areas increases stormwater volume making a planned conveyance system necessary.

Stormwater conveyance systems dispose of stormwater in a controlled fashion by directing runoff along stabilized paths controlled with channel stabilization and outlet protection.

OPEN CHANNEL STABILIZATION

Description and Purpose

Properly designed stabilized surface drainageways convey stormwater in urbanizing areas without becoming eroded. To prevent erosion and gullying, channel lengths and outlets can be stabilized by lining with vegetation or structural materials such as riprap, concrete or bituminous paving. Grade control structures, sediment traps and basins are often used with channel lining to aid with stabilization.

Target Applications

Protection is used to deal with increasing flow from urbanization. Target pollutants are sediment and associated pollutants generated from erosion.

Effectiveness

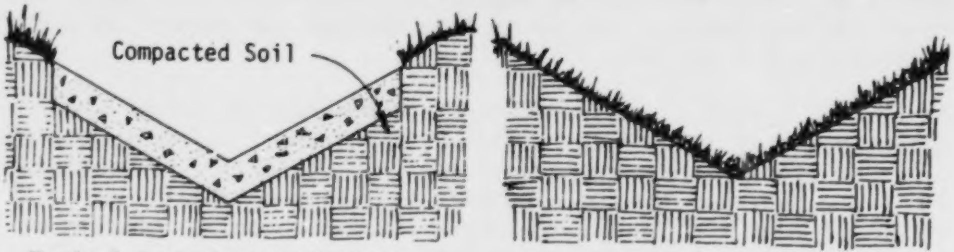
Channel stabilization has a variable effect on protecting water quality. Channel lining may reduce channel erosion up to 99 percent but will not necessarily reduce existing sediment loads. The use of grade control structures, sediment traps and sediment basins will provide benefits in water sediment reduction, as well as channel stabilization (see the appropriate sections).

Planning Considerations

The choice of channel stabilization measures depends on slope, velocity, flow frequency, soil and cost. Following are examples of drainageway stabilization techniques and Figure 7 shows typical cross-sections:

- Earthen lining is inexpensive, but relatively ineffective. It has limited applications, being usable only on sections with low gradients. Allowable flow velocities vary with soil type but they are generally very low. Fine soils are stable only with flow velocities below 2.5 feet per second, while coarse gravel can be subjected to velocities up to six feet per second (Virginia SWCC, 1980).

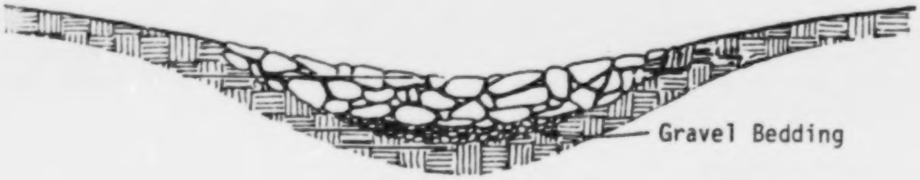
- Vegetation stabilization is best used on small channels with gentle side slopes, low gradients, low velocities and infrequent high flows. Besides reducing channel erosion and gullying, grassed waterways have secondary benefits of reducing flow velocity, increasing infiltration, removing suspended solids and being visually pleasing. For maximum benefit, vegetation must be maintained at full growth. Waterways are shaped or graded to aid



Typical Concrete-Lined Ditch

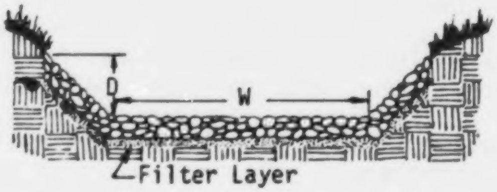
Typical Grass-Lined Ditch

TYPICAL "V" CROSS-SECTIONS



Parabolic-Shaped Waterway with Stone Center Drain

PARABOLIC WATERWAY CROSS-SECTION



Typical Riprap Channel

TRAPEZOIDAL WATERWAY CROSS-SECTIONS

Figure 7. Typical Waterway Cross-sections.
Source: Virginia SWCC, 1980.

vegetation establishment across the whole cross section. Vegetation can be established by sodding or seeding, though seeded grass is more difficult to establish. When introducing vegetation, erosion control mats, mulches or other control measures can be used to improve the chances of successfully stabilizing the channel.

- Structural lining is used when vegetation cannot be established in a drainageway because of long flow duration, high runoff velocities, erodible soils or steep slopes. Riprap lining is used for its nonerodible surface, low cost, somewhat aesthetic natural appeal, permeability and high surface roughness (see Structural Streambank Stabilization). Concrete or asphalt linings are less appealing since they tend to be visually unattractive and impermeable.

- Grade control structures reduce runoff velocities in drainageways by reducing the channel gradient and dissipating the resulting energy. Structural methods include spillways, drop pipes, chutes and flumes. Grade control structures are best used when dealing with large volumes of runoff, steep gradients or unstable areas where vegetating is impractical.

- Sediment basins protect stream channels by collecting runoff and releasing it at nonerosive rates. Basins provide effective sediment removal and flow control but require large land areas and have high O & M costs for removal of accumulating sediments (see the Detention section).

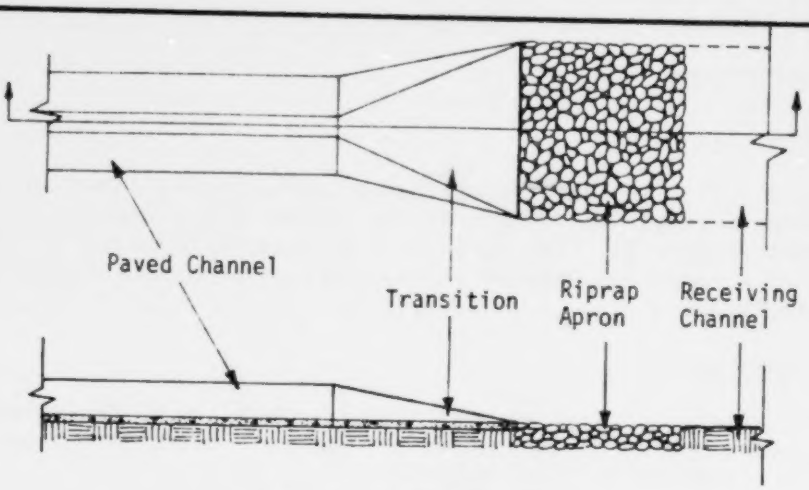
Design Considerations

Construction difficulties depend on the stabilization measures taken. For instance, while vegetation is being established or a structure is being constructed, water flowing into the site can cause problems. This can be solved by establishing stabilization measures before connecting channels are built to direct water into the channel or by building temporary diversions to prevent water from entering the site.

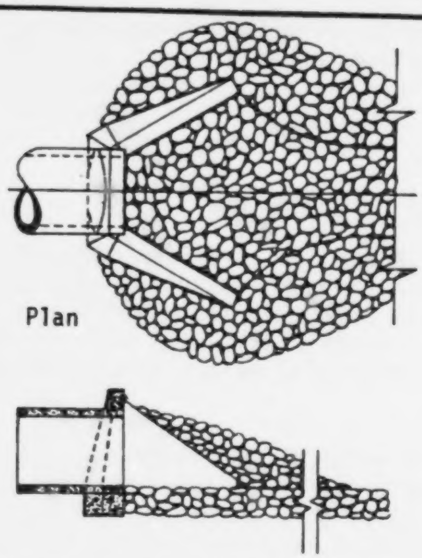
Open channel stabilization may incorporate several methods along different sections of a channel. The effects that a stabilization measure has both upstream and downstream must be considered to assure that protection at one point does not result in increased damage elsewhere on the channel. A grade control structure is designed for a higher capacity than vegetative measures since overflow may severly damage the structure. To prevent scouring around the structure, additional stabilization measures may be implemented to reduce erosion that might undermine the structure.

The cost of each measure is dependent on material costs, equipment access and labor costs. Channel stabilization costs between \$60-105 per foot (Oberts, 1982), with material costs as follows (Virginia SWCC, 1980):

Material	Estimated Material Costs
Grass lined	
seeded	\$ 2-6 yd.^{2}
sodded	9-12 yd.^{2}
Riprap	30-56 yd.^{2}
Concrete or asphalt paving	25-37 yd.^{2}



PAVED CHANNEL OUTLET



Pipe Outlet To Well-Defined Channel

PIPE OUTLET CONDITIONS

Figure 8. Methods of Outlet Protection.
Source: Virginia SWCC, 1980.

O & M needs are to maintain the vegetation or structure in its initial condition (see Streambank Stabilization).

OUTLET PROTECTION

Description and Purpose

Outlet protection includes vegetative or structurally lined aprons or acceptable energy dissipation devices at the outlet of a lined channel section, pipe or culvert (Figure 8). The purpose is to prevent scouring at the point of entry into a receiving channel and to reduce downstream erosion by reducing flow velocities.

Target Applications

Outlet protection is applied when the flow velocity of the outlet will exceed the desired velocity of the receiving channel. Outlet areas are considered as points of potential critical erosion.

Effectiveness

Outlets can be designed to effectively reduce velocity and protect against erosion, but they do not always provide a positive effect on water quality. The use of other methods, such as sedimentation basins and drop boxes, provides more effective removal of water sediment loads (see Detention and Energy Dissipation sections).

Planning Considerations

Outlet protection can be applied as a flow transition structure where the flow velocity is reduced by dissipating excess energy while discharging to the receiving waters. A common device is an apron lined with riprap or concrete. Outlet aprons are best used for low flows where a zero gradient section is sufficient to reduce outlet velocities to a level acceptable for the receiving water.

Other methods of outlet protection include vegetative outlet protection used with very low flows and velocities; sedimentation basins appropriately used when large flows make aprons uneconomical; and energy dissipating structures which best deal with situations where a large grade must be controlled.

Permit requirements may be in effect to force compliance with certain design specifications.

Design Considerations

To reduce difficulties of dealing with flow during construction, outlet protection can be incorporated before waterways are completed. Alternatively, temporary diversions can be implemented to keep runoff away during construction.

Outlets should be designed by a qualified person who can follow design standards and provide an outlet that has no overflow at the end of the paved section, proper alignment between channel and outlet, and a design that provides the required transition between outlet and receiving water depths and velocities.

STRUCTURAL SLOPE STABILIZATION

DEFINITION AND PURPOSE

Mechanical slope stabilization in the form of retaining walls, benching and terracing or regrading are used on oversteepened slopes to reduce erosion and sedimentation. Soil surface preparation methods such as surface roughening and surface grading are combined with structural controls to stabilize slopes. Slopes may be reshaped or regraded before structures are constructed.

TARGET APPLICATIONS

The target pollutants are sediments that result from slope erosion. Structural methods are usually applied only when vegetating methods will not be adequate. Typical applications are oversteepened, unvegetated slopes with inadequate drainage. Slopes in need of stabilization include slopes cut or filled for road or highway construction, gravel pits, quarries or other mining operations, and slopes created during building construction.

EFFECTIVENESS

Slope stabilization will reduce sediment loading from erosion, but does not have a measurable direct effect on water quality. The effectiveness of structural methods for slope stabilization vary with site and application method.

PLANNING CONSIDERATIONS

Since vegetation is the cheapest and most effective stabilization measure available, structural methods are best used to provide the minimum slope stabilization required to successfully establish vegetation. Structural slope stabilization design should be approved by a qualified engineer. Design should take into account all site specific problems or restrictions.

Regrading a slope is used in combination with structures to reduce slope steepness. The use of combined measures reduces the need for major slope reworking, leveling or lengthening that may be impractical. Grading is best used to reduce slopes above the angle of natural repose, that is the angle at which internal friction of the soil particles allows them to reside stably.

Reshaping a slope to create terracing or benching is a method of modifying a slope to minimize runoff erosion. Terraces provide stable surfaces for vegetation and reduce erosion by diverting runoff from steep slopes and directing it to nonerosive drainage channels, checking runoff flow, collecting sediments, increasing runoff distance of overland flow and lowering runoff velocity. Slope length requirements may limit the use of reshaping a slope.

Slope bottom benching is leaving a gently sloping surface at the base of a steeper slope to retain eroded materials. This method is best used on small oversteepened slopes that cannot be regraded because of access or construction problems. Slope stepping is a continuous series of horizontal steps cut into the slope face to interrupt the slope length and provide a stabilized bench capable of sustaining vegetation.

A retaining wall is a structure built of rock, wood or concrete to physically stabilize an oversteepened slope. Design considerations include wall height, rock diameter, solid nonerodible foundation, rock placement, slope (length and gradient) and when required a drainage system. Retaining walls are generally used to stabilize the toe of a steep eroding slope. If the final slope will be too steep, a retaining wall can be placed at the base of a slope which will reduce the elevation drop over the existing slope and allow the regrading of a milder slope. A retaining wall may also be placed to preserve an existing mild slope after a cut has been made at the base.

- Rock retaining walls are low gravity walls constructed of large rock materials. Rock walls can be constructed to retain a somewhat natural slope appearance. Landscaping plans often utilize rock walls as an aesthetically attractive way to stabilize a steep soil. Rock walls are best used at low heights to stabilize a slope so that it may be regraded to a milder gradient without lengthening the slope.

- Wood retaining walls should be made with a sturdy readily available supply of wood. A wood retaining wall is best used for a low structure on a steep slope of loose materials underlain by rigid rock or firm subsoil to securely anchor the wall. Commonly used woods include railroad ties or redwood planks, though the use of redwood may represent a misallocation of a limited resource. Installation requires some carpentry work which may increase the labor costs. Costs of redwood fencing were determined to be high with two-thirds of the total cost allocated to materials. A cheap readily available lumber supply would bring the total cost within a more competitive price range.

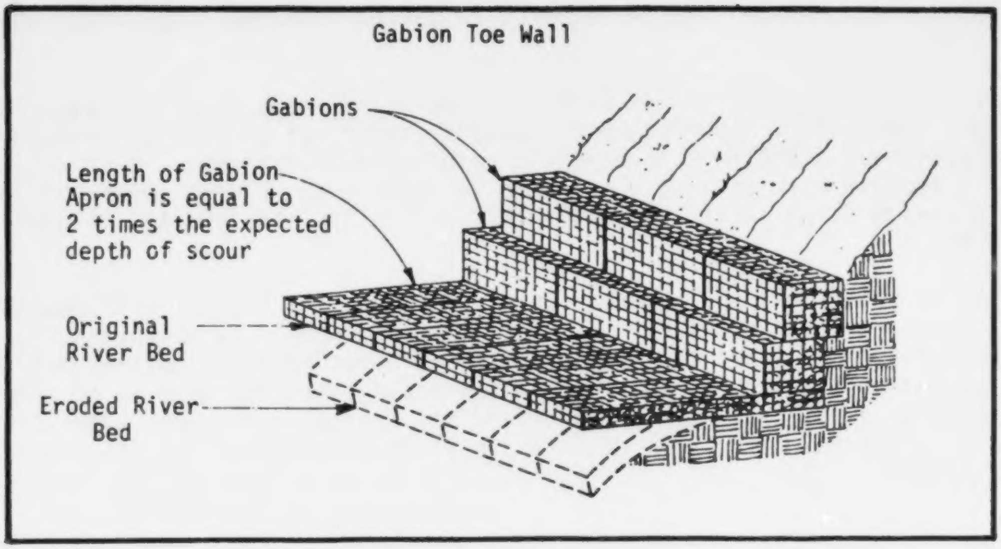
- Concrete retaining walls create a relatively unnatural appearance. Due to labor and material requirements, concrete is a costly method. The use of concrete retaining walls is limited by cost, site accessibility and the need for stable foundations.

Gabions are large single or multicelled rectangular wire boxes filled with rock and wired together for permanent slope or drainage stabilization. They are used to stabilize steep slope faces, weirs, channel linings and waterway outlets (Figure 9). Gabions are particularly useful where seepage is expected since they are permeable. Gabions can use smaller rocks than rock retaining walls so that, unlike retaining walls, water can filter through but earth is held back. Gabions have a positive effect of filling with soil and providing a surface where vegetation might grow. Negatively, gabions are considered unattractive and are difficult to stabilize when more than two tiers are required.

Revetments are artifical structures devised to aid in establishing a slope steeper than the natural angle. Revetments completely cover the unstable slope and provide permanent stabilization without revegetation. Depending on the type of revetment, problems of impermeability, inflexibility, heavy weight and unnatural appearance can occur. Actual costs depend on transportation, site accessibility, labor costs and site character. High material and installation costs generally limit the application of revetments as a general slope stabilization method.

DESIGN CONSIDERATIONS

Seepage complicates the construction of control measures. Seepage may contribute to soil slippage on the surface face or structural failure. Hydrostatic pressure build-up behind impervious structures should be released by a properly


Gabion Toe Wall
Gabions
Length of Gabion Apron is equal to 2 times the expected depth of scour
Original River Bed
Eroded River Bed

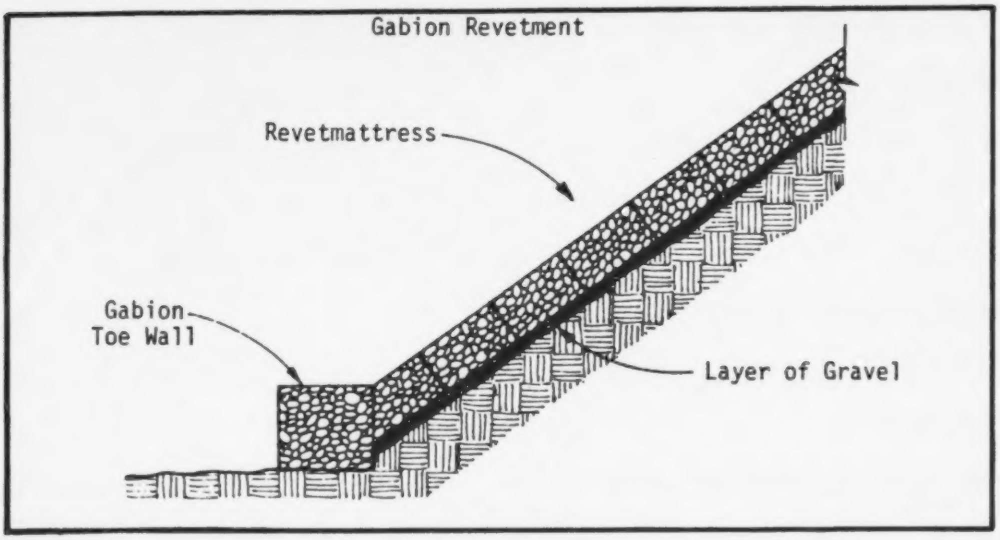


Figure 9. Applications of Gabions.
Source: Vrginia SWCC, 1980.

installed drainage system. When adjacent to an impervious surface, a structural drainage system may be required to prevent erosion or undercutting at wall foundations.

Difficulties in constructing anchoring for higher structures may encourage height limitations. For example, gabions should not be stacked higher than two tiers without additional bracing and reinforced foundations. Rock retaining walls require careful construction to be effective. Sloppy construction, such as allowing large spaces between rocks, will allow soil erosion through the cracks.

Costs vary with material price, labor and site installation (site accessibility, area covered). The cost of using methods that allow regrading for the reduction in slope are usually justified by a reduction in maintenance costs of an oversteepened slope. The most cost-effective methods seem to be those aimed at utilizing vegetative stabilization after minimal structural alterations. Costs of several structural methods are as follows (Lynard et al., 1980; White and Franks, 1978):

	Slope Stabilization Equivalent Costs ($ per foot)			
Method	Materials	Equipment	Labor	Total
Rock retaining wall				
2 ft. manually placed	$ 2	$ 1	$ 12	$ 15
4 ft. mechanically loaded	5-7	12-14	14-16	31-37
Gabion retaining wall				
3 ft.	13	11	4	28
6-9 ft.	23-37	6-9	31-50	60-96
Concrete retaining wall (4 ft.)	--	--	--	66
Revetments (cost per sq. yd.)	--	--	--	12-33
Slope benching	0	7	3	10
Slope stepping (cost per acre)	0	425	330	755

CONSTRUCTION ON-SITE

CONTROL SITE DISTURBANCES

DESCRIPTION AND PURPOSE

Construction activities disturb natural waterways and soil surfaces. By controlling such disturbances pollution from construction sites can be limited. Activities that should be controlled include construction traffic, chemical use and soil exposure. Construction traffic disturbances are controlled by stabilizing access roads and stream crossings. Chemical use is controlled by limiting use, or applying sediment and erosion control devices. Soil exposure or disturbances are controlled by minimizing vegetative clearing and grading, phasing development and dust control.

TARGET APPLICATIONS

Target pollutants are sediments and associated nutrients, construction chemicals and dust. Control of site disturbances should be considered for every construction project in the planning stages. Most methods of controlling site disturbance must be planned before construction begins, as is the case for phased development or stabilized construction roads. Once construction begins standard erosion control methods are utilized.

EFFECTIVENESS

Controlling site disturbances reduces some of the additional pollution loading generated by construction. The control of disturbances, vehicle traffic, chemical application and soil exposure have an undetermined effectiveness at protecting water quality. If properly used they should, however, significantly reduce erosion as well as the conveyance of chemicals, nutrients and sediment to a waterbody.

PLANNING CONSIDERATIONS

Specific methods of controlling site disturbances can be applied to construction traffic, chemical use and soil exposure. Construction traffic will disturb the soil unless stream crossings and roads are stabilized. As construction vehicles travel through drainageways, they churn up sediments, promote erosion and interfere with drainage. To combat this type of disturbance a temporary crossing can be applied to significant drainageways. The control is usually a conduit through an earth fill which allows water to pass under the roadway without disturbance from construction equipment.

To control site disturbances by construction equipment, traffic can be routed along a stabilized road. Site access roads exposed to frequent construction traffic or heavy construction equipment have a high roadbed erosion rate, especially during wet seasons. Roads should be temporarily stabilized with gravel immediately after grading which should result in improved road conditions and decreased sediment transport.

A temporary construction entrance can be placed to prevent the tracking of sediment from the site onto a public road. An entrance constructed from coarse aggregate can be applied wherever traffic leaves a construction site and goes directly to a public road or paved area. If this is not effective at preventing transportation of mud and dirt from the site, the public road should be swept frequently. Alternatively the vehicle tires can be cleaned before exiting from the site and proper drainage provided to handle the sediment laden wash water.

A variety of chemicals are used during construction that represent potential pollutants. Chemicals that may degrade water quality include pesticides, fertilizers, petroleum products, solid wastes, building products and sanitary wastes. Methods of limiting chemical disturbances include sediment and erosion controls, and controlled use. Depending on the chemical, transportation offsite by runoff water can occur in a soluble, or particulate form (adsorbed to sediments).

Erosion controls limit soil exposure to runoff and subsequent transport to waterways. Sediment controls trap particulates and chemicals associated with particulates. Once present in stormwater runoff pollutants such as pesticides, nutrients and others are difficult to remove. The most economical and effective control for these chemicals is to follow recommended application, disposal and storage procedures.

Regulation of use and disposal of chemicals exists in the form of federal, state and, often, local ordinances. Regulations may vary from federal banning of a highly toxic pesticide to local litter law that applies to construction waste. For greater compliance with regulations, developers, engineers, planners and construction workers should all be aware of chemical use controls.

During construction the soil surface is exposed leaving it vulnerable to dust and sediment disturbance. Several regulatory ordinances usually exist at the local level to limit problems associated with soil exposure. Grading ordinances regulate land disturbance and dust and noise ordinances require controls on these site disturbances to limit their impact on surrounding property. Soil erosion can be reduced by phased development, limited grading and dust controls.

Development can be phased so that only areas which are being actively developed are exposed. Clearing, constructing and restabilizing activities are timed to limit the duration of soil exposure and the size of the area exposed.

Clearing and grading should be kept to a minimum, not only to limit erosion by preserving vegetation, but also keep natural drainageways intact to control runoff. Grading can be used to maintain gentle slopes that will reduce runoff velocities and resulting erosion.

Dust controls prevent wind from eroding exposed soil surfaces. Reducing airborne particles cuts down unpleasant dust and the possibility of future water sediment loading from these particles. Wind breaks and soil stabilization methods (dust suppressing chemicals, water sprinkling, ground cover) provide dust control on construction sites.

DESIGN CONSIDERATIONS

The design considerations of controlling site disturbances depend on the site. The first step is to identify potential disturbances and then develop a suitable control plan. In most cases controls are planned before a disturbance occurs, as a preventive measure. Benefits of using phased development include well coordinated construction activities, reduction of future expenditures to control and repair erosion damage, fewer initial costs for on-site erosion control and a more aesthetic finished development.

SLOPE STABILIZATION

DESCRIPTION AND PURPOSE

Slope stabilization used to control erosion associated with construction includes both vegetation and structural methods. Vegetation is the most commonly used and least expensive method of reducing erosion and can be used during or after construction operations. Vegetation combines well with other erosion control measures, such as diversions to stabilize them and increase their erosion reduction potential. Methods of erosion control implemented during construction include soil preparation, vegetation, mulching and erosion control mats. For details see appropriate sections under erosion control.

SEDIMENT BARRIERS

Sediment barriers are temporary measures used at construction sites to control runoff by promoting velocity reduction and subsequent sediment deposition. They intercept runoff from exposed land areas and retain part of the sediment load. They also decrease the velocity of sheet flows or low to moderate level channel flows. Commonly used barriers include strawbales, filter fences, sandbag barriers, brush barriers, and inlet protection. Sediment barriers may be applied in combinations such as straw bales in front of silt fences or straw bales placed as a filter core for log check dams.

STRAW BALE BARRIER

Description and Purpose

A straw bale sediment barrier consists of bound straw or hay bales anchored and entrenched to form a continuous wall (Figure 10). Straw bales provide a pervious barrier which filters runoff and blocks sediment transportation. This temporary barrier has limited effective lifespan of up to three months (Virginia SWCC, 1980).

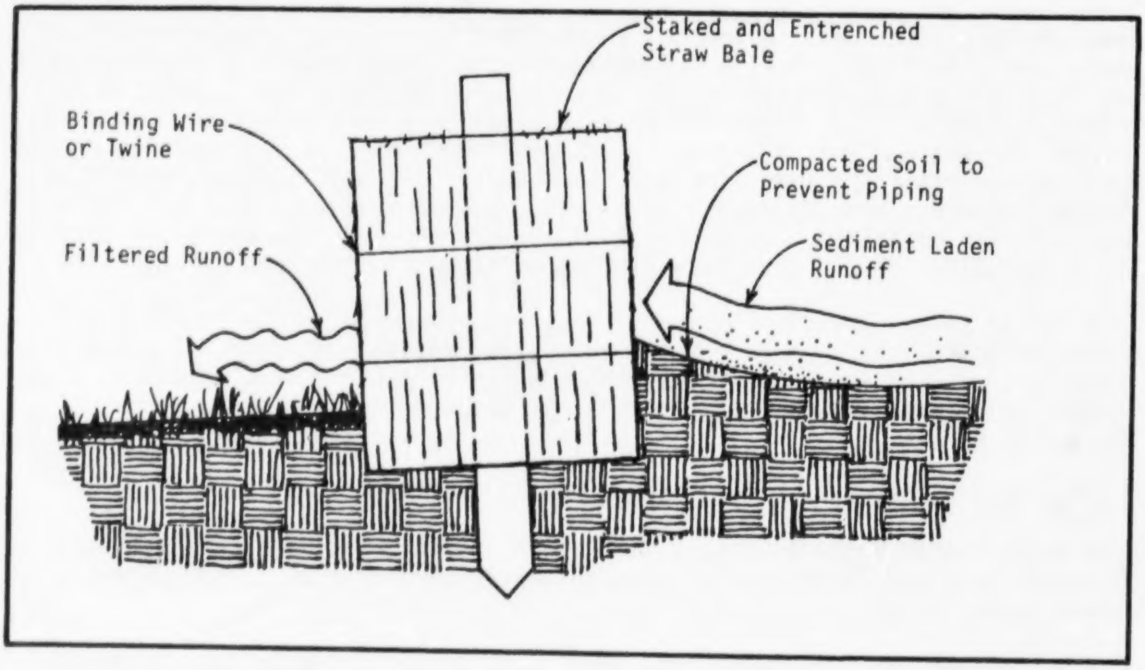


Figure 10. Cross-section of a Properly Installed Straw Bale.
Source: Virgina SWCC, 1980.

Target Applications

Straw bale barriers are aimed at controlling sediment transportation. They are applied on construction sites whenever disturbed areas are contributing sediment. Straw bales are used where sediment laden runoff might leave a site as sheet or channel flow or discharge into a specific point, such as an inlet. Sediment barriers are applied during highway construction, building construction or when a disturbed area is subjected to sheet erosion. Straw bale barriers should not be applied in sites exposed to concentrated flows.

Effectiveness

For maximum efficiency, properly placed straw bales initially reduce 40 to 60 percent of the sediment loading (Stanley Consultants, 1976). In most applications, straw bale barriers provide less value because of improper use, installation and maintenance. One study found trapping efficiencies of a properly placed barrier to drop from 57 percent to 16 percent during one month of no maintenance (Virginia SWCC, 1980). Even when properly used, installed and maintained, straw bales have limited effective life spans which means straw bales are only a temporary measure to improve water quality. Even with truly dedicated maintenance programs effectiveness can drop up to 50 percent over a six-month period.

Planning Considerations

Straw bales are easy to use and require no particular design though improper use provides little aid in improving water quality. To prevent undercutting bales are placed in a shallow excavated trench. Bales should be anchored with at least two stakes or steel pins. A single row of bales can be used to intercept sheet flow. Bales can be stacked up to triple height when used to filter limited concentrated flow though additional wire or pole backing should be used for stabilization. For the best results sediment barriers should be installed before area disturbances begin. Once permanent erosion and drainage controls are established straw bales should be removed. One method of disposal is to manually reapply the straw as a mulch after construction is completed.

The use of straw bales is limited by drainage area size, slope length and gradient behind the barrier. Straw bale barriers are best used below disturbed sloping areas, on construction site boundaries in minor swales or ditches, or around stormwater inlets. They should not be used in waterways or grounds subjected to high flow velocities that may cause a washout.

Design Considerations

The installation costs will vary with labor and material costs. Straw bale barriers have been estimated between $3-10/ft (Lynard et al., 1980; Stanley Consultants, 1976).

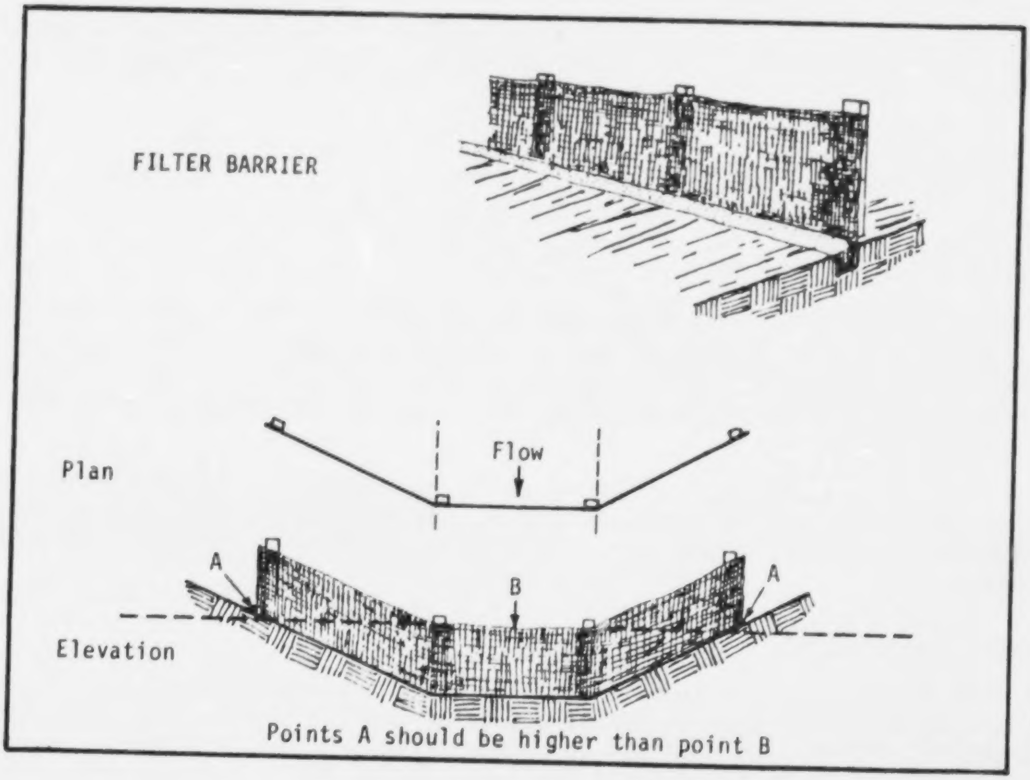
O & M requirements for straw bales start with periodic inspection and maintenance. To retain straw bale usefulness, sediment build up around the bales should be removed, damaged bales repaired, loose hay cleaned up and failed or rotted bales replaced.

Development and use of straw bales is not difficult though improper use, installation and maintenance combined with the fact that straw bales deteriorate quickly can compound pollutant problems. Improperly installed sediment barriers will result in undermining or end flow causing barrier failure or loose hay that may mix with mud and clog waterways and storm sewer inlets. Straw bales are not recommended for use alone, but should be part of a more comprehensive erosion control program.

FILTER FENCE

Description and Purpose

A filter fence is a temporary sediment barrier constructed with posts or wire fencing and filter fabric (Figure 11). The purpose is to intercept and retain sediments and reduce flow velocities of sheet and limited channel flows while on a construction site.



Points A should be higher than point B

Figure 11. Proper Placement of a Filter Barrier in a Drainageway. Source: Virginia SWCC, 1980.

Target Applications

Filter fences are designed to remove suspended solids from runoff water. They are placed below disturbed areas where sheet or rill erosion or low velocity channel flows cause runoff flows to be loaded with sediment. Specific applications include highway and buildings construction sites, unstable cut or fill areas or any other disturbed area subjected to sheet or rill erosion.

Effectiveness

Studies have found that silt fences trap a higher percentage of suspended solids then straw bales. Silt fences also have lower failure rates though improper installation will substantially reduce sediment removal effectiveness by causing undermining, end flow or barrier failure. Tests to determine the types of suspended solids retained found all materials effectively filtered sandy sediments, while large variations occurred on filtering effectiveness of finer silts and clay particles. The following table demonstrates the effectiveness with which filters remove suspended solids and reduce flow velocities (Virginia SWCC, 1980).

Material	Flow Rate (gal/sq. ft./min.)	Filter Efficiency (percent)
Straw	5.6	61
Burlap	2.4	84
Synthetic fabric	0.3 (avg.)	97 (avg.)

Planning Considerations

Silt fences are best used along the toe of a fill or the downhill side of a large cut area, along streams and in natural drainage areas to reduce sediment quantities and flow velocities to downstream areas. Limitations in use are large drainage areas, long or steep slopes behind the fence or areas with large volumes of flow.

For the best results filter fences should be constructed after clearing the area but before soil disturbance begins. Recommended installation methods, materials and fence dimensions should be followed to insure adequate sediment control.

Design Considerations

A filter fence is only expected to be a temporary measure, three to six months, but some materials such as burlap may deteriorate within one to three months. Synthetic fabrics are expected to remain effective for six months. Woven and non-woven synthetic fabrics are available though tests indicate that woven materials tend to be stronger. Development difficulties might occur depending on differing flow rates through materials. End flow or fence failure may occur where low filter rates and high flow volumes cause ponding behind the barrier.

Filter fences are easy to install. They are particularly useful when space is limited. They require approximately one-fourth the space that straw bales and filter berms require. The initial cost of filter fences is higher than straw bales, but fences have the advantage that some of the materials can be reused.

Initial costs will vary with labor wages and type of material. Filter fences installation costs have been estimated between $3.5-7.5/ft (Virginia SWCC, 1980). O & M is required to keep the fence operating efficiently. Periodic inspection for damage and sediment buildup will indicate the need for maintenance. Frequently required maintenance operations include sediment removal when buildup reaches one half the fence height and repairs of tears from water, wind or construction equipment.

BRUSH BARRIER

Description and Purpose

A brush barrier is a sediment filter constructed in the shape of a berm, composed from residue materials obtained from clearing the site. Filter fabric is often incorporated in the barrier structure to increase its ability to retain sediment and reduce runoff velocities. The purpose is to filter runoff and trap sediments before they are transported from a construction site.

Target Applications

Brush barriers are targeted at removing sediments. It is constructed when a disturbed area is subjected to sheet and rill erosion if adequate residue materials are available. Erosive action of the runoff may be reduced by slowing flow velocities as well as trapping sediments while filtering the runoff water.

Effectiveness

Brush barriers improve water quality by filtering sediments from the runoff waters. The addition of a filter fabric covering greatly enhances the benefits to the surface water by creating a more effective filter.

Planning Considerations

Brush barriers are best applied to the toe of a slope, especially fill slopes provided there is sufficient room for the space consuming barrier, there is no need for an aesthetically pleasing barrier and there are adequate materials available on the site. Brush barriers are also used below culvert outlets to trap sediments. Barriers should be constructed in conjunction with the clearing operation and should be in place before soil disturbance begins.

Design Considerations

Brush barriers are easy to install and use. Constructing a brush barrier requires no specific design only that the barrier not be made of large objects such as logs and that the brush be intwined to form a stable barrier. Generally, a brush barrier is placed along slope contours and has a minimum height and base width. Unlike filter barriers, removal of brush barriers is optional. As a permanent filter measure brush barriers provide organic, fairly stable filter that is unfortunately visually unappealing. Being biodegradable, natural growth will take over the barrier as it rots.

The most likely place for construction difficulties to occur involves the addition of the filter material. Placement requires specific installation procedures to provide an effectively operating filter.

Brush barriers cost less than other types of filter barriers since they utilize site materials that would otherwise be burned or hauled away. Construction requires a combination of both mechanical and manual labor, but generally no expertise is required. The installation cost is estimated at $2-4/ft (Virginia SWCC, 1980).

The O & M needs are less than other types of barriers. Brush barriers being fairly stable require little maintenance, usually just removal of deposited sediments when accumulation reaches one half the barrier height and repair of damage.

INLET PROTECTION

Description and Purpose

Inlet protection is the placement of sediment trapping barriers around a stormwater inlet prior to permanent stabilization of a disturbed area. The purpose is to prevent sediment from entering the storm drainage system in areas under construction.

Target Applications

Inlet protection is installed around drop or curb inlets subjected to sediment laden runoff from a disturbed area (Figure 12). Filter barriers are applied in small drainage areas away from large concentrated runoff, while sediment traps can be used on concentrated runoff.

Effectiveness

Inlet protection barriers prevent sediment from entering storm sewer systems. Effectiveness of inlet filters are comparable to general sediment barriers.

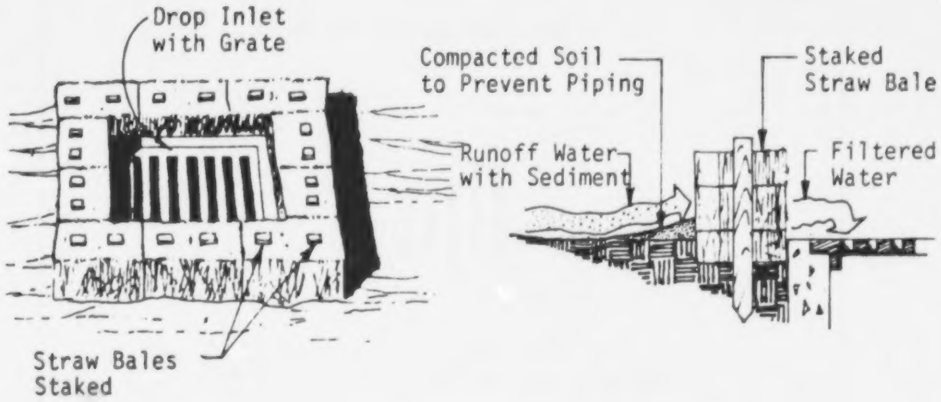
Planning Considerations

Storm sewers built before the surrounding area is stabilized can convey large amounts of sediment to the drainageways. Storm sewer clogging or a reduction in capacity will occur when sediments are deposited within the system. To prevent sediments from entering the sewer system its inlets can be temporarily protected with sediment traps or filter barriers.

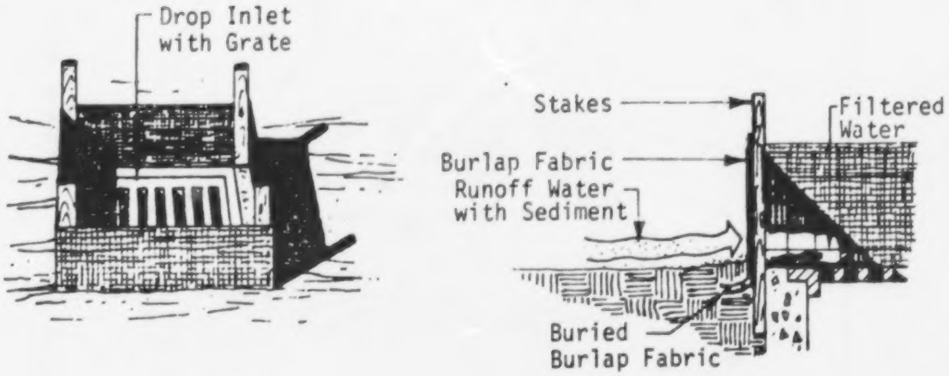
Filter barriers are best used in small runoff areas where concentrated flows are not large. Filter inlet protection is an alternative to sediment traps, which require large surface areas. Where space is limited, filter barriers provide the best protection method.

The varying types of sediment barriers are useful under different circumstances. Specific applications used to collect sediments include straw bales, burlap filter, gravel and mesh filter, block and gravel filter, excavated trap, sod filter and drop inlets (Figure 12).

STRAW BALE DROP INLET SEDIMENT FILTER



BURLAP DROP INLET SEDIMENT FILTER



GRAVEL AND WIRE MESH DROP INLET SEDIMENT FILTER

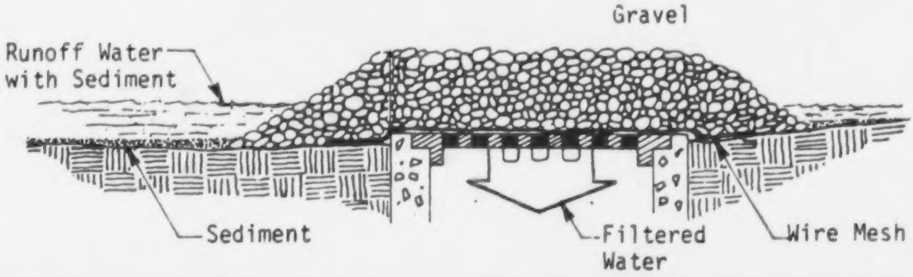


Figure 12. Methods of Inlet Protection. (Page 1 of 2)
Source: Virginia SWCC, 1980.

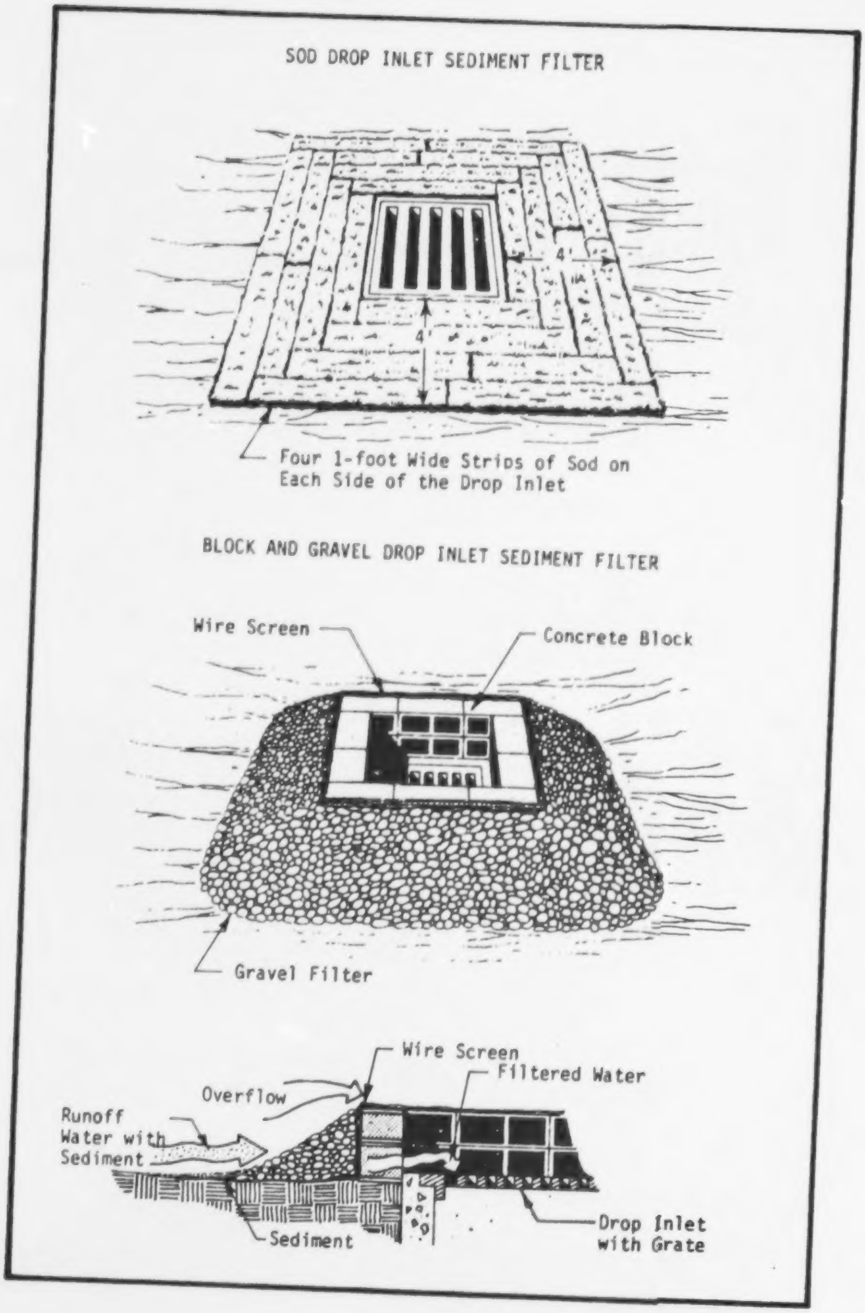

SOD DROP INLET SEDIMENT FILTER
4'
4'
Four 1-foot Wide Strips of Sod on Each Side of the Drop Inlet
BLOCK AND GRAVEL DROP INLET SEDIMENT FILTER
Wire Screen
Concrete Block
Gravel Filter
Wire Screen
Filtered Water
Overflow
Runoff Water with Sediment
Sediment
Drop Inlet with Grate

Figure 12. Methods of Inlet Protection. (Page 2 of 2)
Source: Virginia SWCC, 1980.

- Straw bales or burlap filters are best used around drop drain inlets on relatively flat areas to filter sheet or overland flows with low velocities. They should not be applied to inlets receiving concentrated flows.
- Gravel and mesh filters are best used on either drop or curb inlets that are subjected to heavily concentrated flows, where surrounding areas will not be damaged by ponding.
- Block and gravel filters are applied to drop or curb inlets where heavy flows are expected and where ponding would damage the surrounding area. Block and gravel filters control excess overflow making this a protection method for inlets by buildings, unstable slopes, roadways or fills.
- Excavated traps are best used on inlets with heavy flows that require an overflow capacity to prevent excessive ponding and easy maintenance.
- Sod filter strips are used to protect inlets from sediment and mulch while permanent vegetation is being established.
- Drop inlets are concrete structures designed to collect and direct runoff to conveyance channels. They are constructed with provisions for settlement and retention of suspended sediments. They should be designed by a registered civil engineer.

Design Considerations

Cost is dependent on the size of the drainage area, labor wages and type of inlet. Various costs can be broken down as follows (Virginia SWCC, 1980).

Method	Inlet Protection Costs
Straw bale barrier	$22-90/inlet
Filter fabric barrier	$22-55/inlet
Gravel and filter fabric barrier	$22-55/inlet
Block and gravel barrier	
Drop inlet	$22-45/inlet
Curb inlet	$22-30/inlet
Grassed filter strip	
Drop inlet	$35-75/inlet
Excavated drop inlet	$2.50-5.00/sq. yd.

O & M is essential to provide the necessary protection to storm drain inlets. Maintenance includes periodic inspection and repairs of damage, removal of trapped sediments and removal of the barrier once the surrounding area has been stabilized.

- Straw bale filter and burlap filter barriers are relatively easy to construct and utilize. For more details, see the sections on straw bale barriers and filter fences.
- Gravel and mesh barriers consist of a wire mesh or filter cloth covering the inlet and a coarse aggregate or crushed rods piled on top of the mesh. Difficulties may occur if the gravel is smaller than the mesh size.

Removal of sediments tend to be cumbersome since stones must be removed, cleaned then replaced.

- Block and gravel filter barriers are created by placing concrete blocks around the inlet, covering it with a wire or cloth mesh to prevent gravel from washing through the holes in the concrete blocks, and then piling gravel against the mesh. As with gravel and mesh barriers maintenance to remove sediment is difficult.

- An excavated trap is constructed by digging a basin around the inlet. It should be large enough to provide the minimum storage capacity required for the drainage area. The area required for this method depends on the drainage area size.

- Sod filters are relatively inexpensive, easy to construct, require little or no maintenance, and provide immediate protection. Unfortunately, they should not be utilized during construction since large volumes of sediment might damage the sod.

- Drop inlets can be designed to remove 90 percent of anticipated suspended sediments during design flow conditions (White and Franks, 1978). To retain effectiveness as a sediment control method these inlets require frequent cleaning. The level of maintenance will be determined by the erodability of the watershed area.

ENERGY DISSIPATION

DESCRIPTION AND PURPOSE

Energy dissipators reduce flow velocities by providing rough surfaces or structures that disperse runoff flow energy. They are used during construction to control erosion. By implementing energy dissipators to reduce the erosive forces of site runoff, reduction in erosion is possible. Common dissipation methods are temporary check dams, level spreaders, vegetation and erosion control mats. Further details can be found in the appropriate sections listed under energy dissipation.

SEDIMENT TRAPS

DESCRIPTION AND PURPOSE

Detention methods allow sediments to settle from runoff before discharging into a surface waterway. They can also be used to detain large volumes of runoff to be discharged later at a nonerosive rate. Implementation of detention methods are recommended during construction to deal with the high sediment concentrations in the runoff. Detention facilities can be constructed on-site, either in-line or off-line. The detention method most frequently implemented for construction sites appears to be small-scale off-site ponding. Several other methods used include sediment traps, sediment basins, ponding or ditches. Sediment traps are especially suited for construction sites and are therefore covered in this section. Details for the other methods can be found in the appropriate sections under Detention.

Sediment traps are small storage areas in natural or excavated depressions constructed by placement of a low head dam (commonly an earthen embankment) usually with a crushed rock outlet (Figure 13). The purpose is to detain sediment laden runoff from construction sites long enough to allow large sediment particles to settle out.

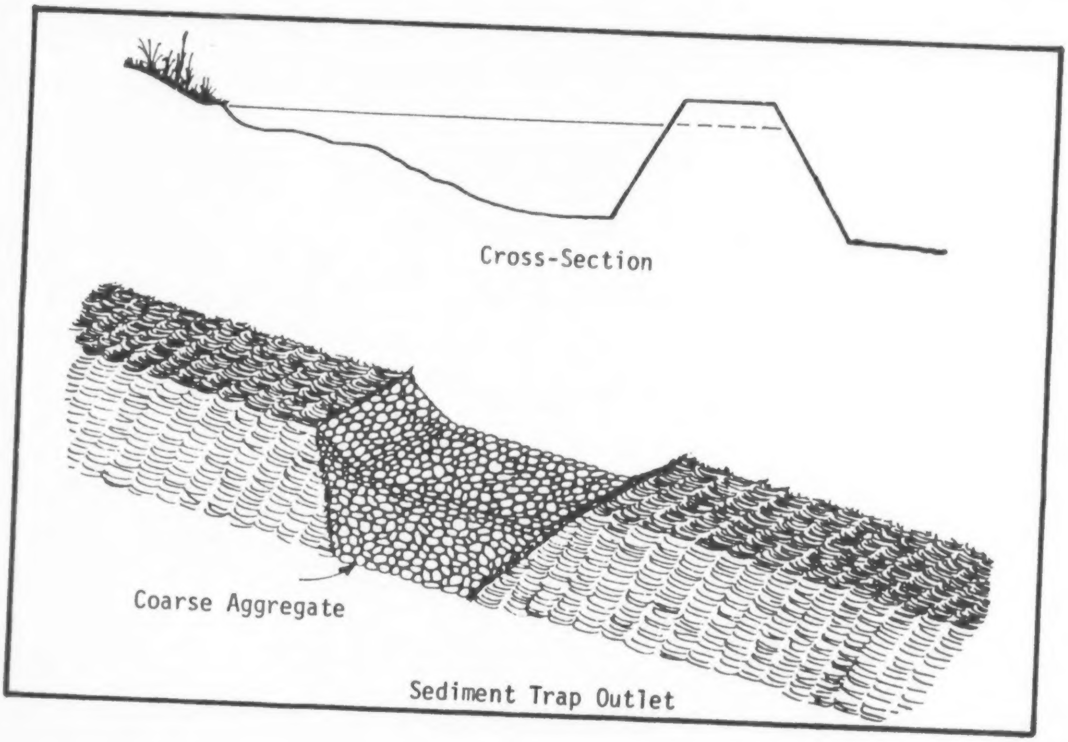


Figure 13. Temporary Sediment Trap with Outlet.
Source: Virginia SWCC, 1980.

TARGET APPLICATIONS

Sediment traps are aimed at removing large particles, that is, sand size or above. Fine particles are not retained without costly additional construction.

Traps are applied before land disturbances take place in the drainage area, and are placed below a small drainage area. They should be built as close as possible to the sediment source and they should be located outside of existing water courses, since they are not meant to control a steady flow. They should not be applied if sediment control will be needed for more than one and a half years or if the drainage area is large.

EFFECTIVENESS

The effectiveness depends on the site, design and construction of the trap. Sediment traps are generally effective at reducing large particles if placed and installed properly, with effectiveness greater than 90 percent possible (Oberts, 1980).

PLANNING CONSIDERATIONS

Sediment traps are similar to temporary sediment basins in operation. The use of several small traps may even replace the construction of a large sediment basin. To provide the correct size and maintenance plan sediment traps should be designed by the project engineer. They should be designed to handle the design storm by varying trap capacity, excavation, embankment and outlet designs.

DESIGN CONSIDERATIONS

The design plans should include final removal procedures as well as maintenance considerations. The trap should be inspected periodically to insure its effectiveness. Sediments must be removed, perhaps as frequenty as after each storm event to maintain effectiveness. The design plan should consider how and where accumulated sediments are going to be disposed of. Once an area is stabilized the sediment trap should be removed. Design plans should include grading and stabilization considerations for trap removal. Costs vary from $2-12 per linear foot with no excavation to $6-18 per linear foot with excavation (Virginia SWCC, 1980).

DIVERSION

DESCRIPTION AND PURPOSE

Diversions are temporary or permanent networks of channels and berms designed to direct water flow from disturbed areas to stable outlets at nonerosive velocities. Diversions can be constructed in different forms. On-slope diversions are laterally constructed channels with a supporting ridge on the downslope side (Figure 14). Excavated ditches or berms provide other types of diversion alternatives.

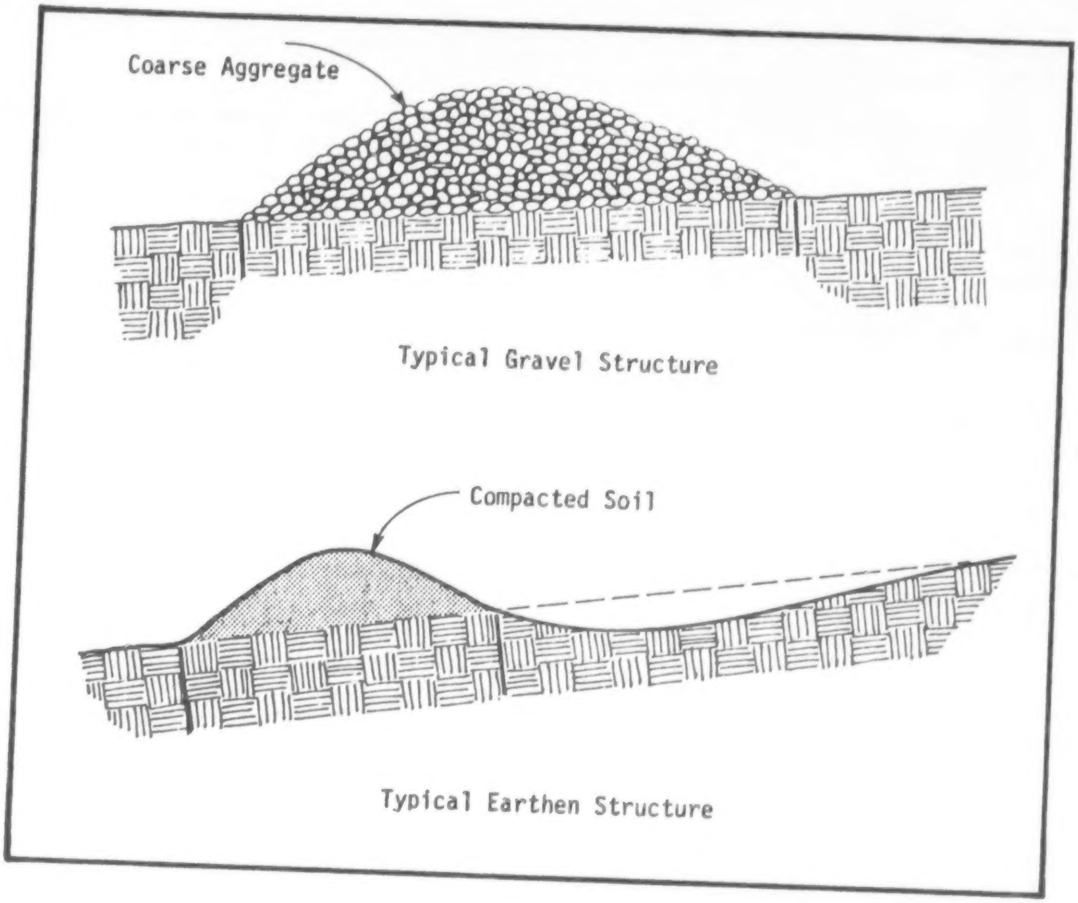


Figure 14. Methods of Temporary Diversion.
Source: Virginia SWCC, 1980.

The purpose of diversion is to intercept and divert sheet and concentrated runoff flows from vulnerable slopes, areas disturbed by construction or urban developments. Stormwater should be directed to stabilized outlets while sediment laden water should be diverted to sediment filtering devices.

TARGET APPLICATIONS

Diversions are applied when runoff over erodible slopes causes erosion and gullying; when surface runoff from higher lying areas may damage lands, streams, roads, structures or buildings; or when surface and shallow subsurface flow is damaging sloping uplands.

Temporary diversions are used to keep flow from construction areas or unstable slopes until permanent measures are in place. They are typically used to protect construction areas such as roadways, building sites or pipelines. They are applied when protection is required for one year or less. The type of temporary diversion will vary with the length of use. Small mounds may be created daily to protect a fill operation while a ditch may be constructed to divert runoff throughout the construction period. Temporary diversions should be installed immediately after clearing or grading is completed, and before construction begins.

Permanent diversions can be installed as a part of the water drainage system to prevent property damage from erosion or flooding. Permanent diversions are typically installed to protect land areas, buildings or agriculture lands. Permanent diversions should not be constructed until after the surrounding area has been stabilized by vegetation establishment or erosion control measures.

EFFECTIVENESS

Diversions do not provide a direct effect on water quality, instead they act to prevent an increase of sediment loading due to erosion of unstable sites. Diversions can also be used to divert highly concentrated flow to treatment areas. The efficiency of diversion practices has been estimated at 50-60 percent reduction in erosion potential (Fitzpatrick et al., 1977). Diversions provide benefits other than protecting water quality since they can be used to prevent erosion and flooding property damage due to excess runoff.

PLANNING CONSIDERATIONS

Diversions are best applied when placement and installation plans are arranged according to site criteria. A formal design is not required for temporary berms, but permanent structures or channels may require a specific design. In either case, design criteria should be considered.

Diversions should be located to minimize interference with, or damage by, construction operations and traffic. The choice of location will depend on outlet conditions, topography, land use, development layout, slope length and soil type. Specific design and installation considerations include adequate capacity for peak runoff values and storm frequencies; limited flow velocity depending on channel lining and soil type; cross sectional shape with acceptable height, width and side slope values; diversion lining, grade and alignment; and outlet conditions.

To provide the best results excess water must be diverted to a stable outlet at a nonerosive velocity. Common methods of disposing of the runoff are, discharging into a lined channel, storm sewer, slope drain, or discharging at a nonerosive velocity through a level spreader, sediment control device, or to an undisturbed stabilized area.

Temporary diversions are best used to protect construction areas such as building sites and roadways. They are generally used only in sites that need protection for a limited time span.

Permanent diversions should not be constructed until after the surrounding area is stabilized. They should be protected from sediment laden runoff with filter strips or sediment barriers and should be lined by vegetation or structural methods to prevent erosion of the diversion structure.

The type of diversion often dictates how it is best used. Three commonly used types of diversions are berms, ditches and combined diversions.

o A diversion berm or dike is a ridge of compacted embankment material. Berms are constructed at the top of a fill slope to divert sheet flow away from an unprotected slope or at the base of a slope to divert sediment laden runoff to a sediment trapping structure. An alternative to the earthen berm is a permeable filter berm (Figure 15). A filter berm is constructed with materials that allow filtering of runoff and retention of sediments. They can be constructed with gravel over a sand core or filter fabric over gravel.

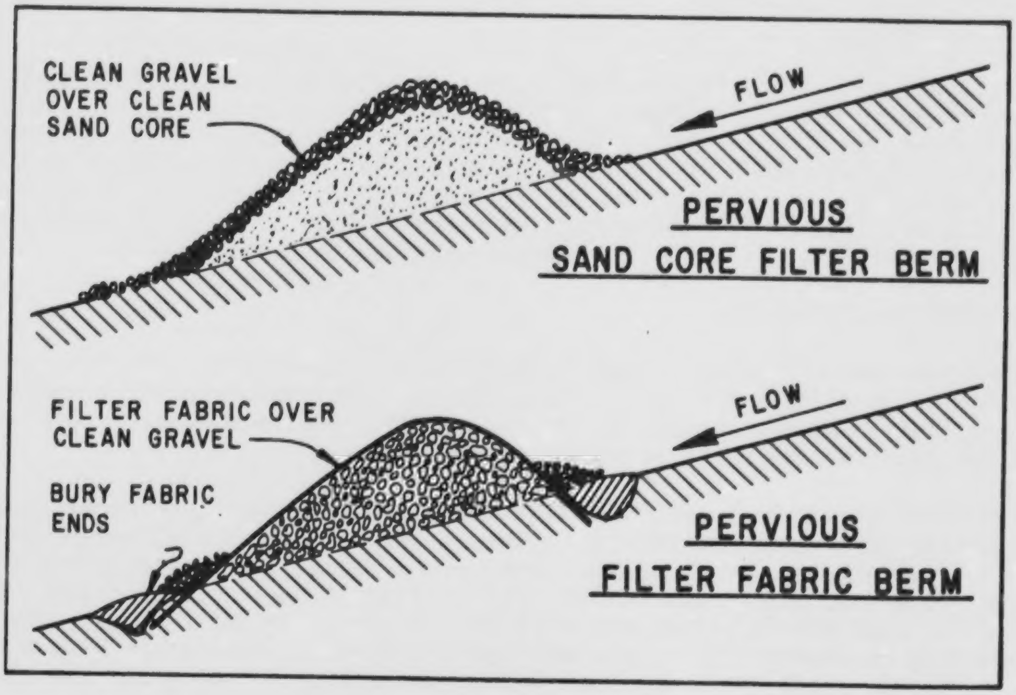


Figure 15. Typical Pervious Filter Berm Designs.
Source: White and Franks, 1978.

Filter berms are best used on heavily travelled right-of-ways or in drainage ditches prior to stabilization of the surrounding area. Berms or dikes can be used to protect a specific site of erosion; placed above an active gully, a berm will divert concentrated runoff from the eroding area.

Berms are also constructed across cleared right-of-ways to shorten the flow length of a disturbed area and divert runoff to a stabilized outlet. They are installed at intervals immediately after grading. An earthen berm is used when there will be little or no construction traffic and a filter berm is applied to areas which must accommodate vehicular traffic.

- A diversion channel is often a shallow trench, swale or ditch (see Figure 14). They collect and divert runoff and with additional design criteria may be incorporated into the permanent drainage system. Temporary channels can be earthen, vegetated or structurally lined depending on the use and intended lifespan.

  Ditches are best used at the top of a cut slope, at the top of embankments, in excavated areas or near the base of cleared sloping areas. Diversion channels provide a temporary drainage system capable of disposing of excess stormwater which prevents water accumulation on the construction site, minimizes regrading required because of erosion and prevents clogging of incomplete storm drainage systems from sediment laden runoff.

- A combined diversion is a channel constructed laterally across a slope with a supporting ridge on the lower side. This type of diversion is used when ordinary berms or ditches are inadequate. As a permanent diversion it is constructed at intervals across a slope to reduce erosion by shortening the length of a sloping drainage path and convey runoff laterally at a reduced velocity to a safe point of discharge. As a temporary diversion, it is used on an active earth fill to protect the unstabilized slope. This type of diversion is used when berms would interfere with fill operations.

DESIGN CONSIDERATIONS

The cost of a diversion structure is site specific. The type of structure, amount of footage required and construction access are all determined by the site. Diversion installations may cost between $1.25-12.55 per foot (Virginia SWCC, 1980).

Temporary berms are the most economical since they are built by piling and compacting dirt from the site and can be constructed with site grading or construction equipment. Filter berms are the most expensive to install since they require materials not found on site and are the most complicated diversions to construct.

O & M needs include periodic inspection and repair when necessary as well as additional inspection for damage after significant rainfall. Immediate and proper construction of a diversion will save money both in repairing uncontrolled erosion and maintaining the diversion.

Maintenance requirements vary by site and diversion type. Diversions immediately adjacent to construction activities should be reconstructed if damaged during the work day. Some diversions require extra maintenance. Filter berms remove sediments and slow velocities as well as divert runoff, therefore, they must be cleaned to prevent clogging by sediments. Ditches may need sediment removal if located around sediment laden runoff.

Temporary diversions will deteriorate faster than permanent diversions, but since they are not expected to last they require less maintenance. Temporary diversions have additional costs of removal once permanent stabilization has been completed and established. Diversions where vegetation failed should be reseeded. Permanent diversions will need maintenance of vegetation or structural lining to prevent erosion of the berm itself.

The ease with which diversions are developed and used depends on the requirements of the site. Diversions should be constructed to provide a positive grade to assure drainage. Unless the diversion slope is large enough to dispose of runoff, water may be stored around the diversion. Water storage would not only require space and increase erosion around the diversion, it would promote seepage which causes soil instability. The diversion slope should not be too great or erosion due to high flow velocities will occur. Steps should be taken to preserve the diversion. Any diversion that will be operating for any length of time should be stabilized with temporary or permanent seeding, mulching or structurally stabilized. To prevent failure, berms and dikes should be adequately compacted.

Construction of diversions require no expertise and can be done by a machine operator. Planning the placement of a diversion requires some knowledge of effective diversions. A poorly placed diversion will not reduce erosion but may actually promote it. For instance, a diversion may intercept sheet flow but discharge concentrated flow. If the diversion is poorly placed, discharge directly on the fill may create deep gullies.

The expertise required to plan a diversion depends on how much damage will occur from diversion failure. Little expertise is required to construct a temporary diversion for a small drainage area to protect nonessential property, while a more experienced person would be needed to plan a diversion to protect essential property. Construction site diversions are usually designed by the project engineer.

To prevent construction difficulties, limitations on diversion use should be followed. Difficulties may arise from unstable outlets, site, slope or soil problems. Unstable outlets will allow erosion to occur at the end of the diversion. Diversions should only be used to control runoff from small drainage areas. They should not be installed on or below extremely steep slopes unless they have been previously stabilized. Diversions should not be substituted for grade stabilization structures used to obtain slope stability. Temporary diversions that must be removed may cause additional disturbances and minor damage to permanent facilities.

SLOPE DRAIN

DESCRIPTION AND PURPOSE

A slope drain is a temporary conduit or tubing extending down a slope. It is constructed from flexible tubing, plastic corrugated metal or any other material capable of providing adequate erosion control.

The purpose is to temporarily convey concentrated runoff down a steep unstable slope without causing erosion. Slope drains are typically associated with construction as a temporary method of handling runoff on unstable cut or fill slopes until permanent measures are installed.

TARGET APPLICATIONS

Slope drains are aimed at reducing sediment loads by reducing runoff water contact with unstable slopes, especially steep, cut or fill slopes. They are applied when a time lag exists between initial slope exposure and final slope stabilization or permanent drainage system installation. Several specific applications when slope drains are used include road construction projects, outlets for diversions and steep fill slopes subjected to large quantities of runoff.

EFFECTIVENESS

Slope drains do not directly influence water quality, but by reducing slope erosion they do prevent some sediment loading. In some circumstances sectional downdrains have been estimated as providing 50-60 percent erosion control (Oberts, 1980).

PLANNING CONSIDERATIONS

This practice is best used on highly erodible fill slopes in conjunction with a diversion network to deliver runoff from the inlet at the top of the slope to the stabilized outlet at the bottom of the slope. Slope drains are generally reserved for particularly steep slopes since gentler slopes can be stabilzed with vegetation.

No formal design is required for slope drains though certain criteria exist to insure effective erosion control. Conditions that should be considered when planning a slope drain include, maximum drainage area, drain size with a diameter adequate to handle the maximum runoff volume and placement that coordinates with diversions and other runoff controls. Installation procedures require that the entire length of the slope drain should be securely anchored and the inlet and outlet adequately constructed to prevent leakage or failure. The inlet should be entrenched and the outlet protected with an energy dissipation and sediment trap to control outflow.

DESIGN CONSIDERATIONS

Construction site slope drains are temporary measures using common materials such as polyethylene sheeting and metal or plastic pipe instead of costly asphalt or concrete drainageway. The inital cost of a slope drain varies with the type of drain installed. Temporary flexible tubing was estimated at $2-6 per foot (Virginia SWCC, 1980) while more expensive concrete sectional down drains can cost around $20-33 per foot (Oberts, 1980).

The contractor is usually responsible for the O&M of the slope drain. Maintenance needs include periodic inspection for clogging and displacement and additional inspection after major storms to insure proper operation. Slope drains are considered temporary methods and should be removed after the slope is stabilized. In the few cases where slope drains are constructed from more permanent materials, such as asphalt or concrete, they can remain as a permanent drainage structure.

Slope drains can be easily developed and used during construction operations, but should not be installed where they will interrupt or disturb construction activities. To prevent difficulties slope drains should be securely staked on compacted fill or undisturbed soil and all connections should be made watertight.

INFILTRATION

INFILTRATION DRAINAGE

Infiltration drainage represents the use of pervious drainage methods to dispose of excess stormwater runoff. These systems reduce the flow discharged to surface waterways by promoting infiltration. These drainage systems improve water quality two different ways. First, by detaining storm runoff, peak flows are avoided and erosive damage and associated sediment loadings are reduced. Second, as the excess stormwater percolates through the soil, natural filtration removes many pollutants: caution must be stressed here to avoid contamination of groundwater system. Methods include grass lined or gravel filled drainageways and ponds or the placement of subsurface drains.

GRASSED SWALE

Description and Purpose

Swale drainage consists of shallow depressions which are vegetated with grass. Vegetated surfaces reduce runoff velocities, enhance infiltration to groundwater, filter runoff contaminents and control erosion. The purpose of applying grassed swales is to retain and percolate stormwater runoff resulting in reduced runoff and recharged groundwater.

Target Application

Grassed swales should be applied only when soil conditions, land uses and pollution hazards are acceptable. For usefulness as an infiltration MP, soils must provide a reasonable amount of permeability. Grassed swales require more space then conventional systems and are therefore applied before an area is completely developed. Caution should be taken so that the groundwater is not threatened by the increase in runoff percolation and the transport of associated contaminents to the aquifer.

Effectiveness

Grassed swales improve water quality by filtering particulates and by reducing runoff volumes. Under optimal conditions, swales like sodded ditches remove up to 50-60 percent of the sediments in runoff (Oberts, 1981). Peak flow discharges to drainage systems during a 10-year storm can be reduced by about 25 percent due to swale storage and infiltration (inlet boxes included). The actual water quality effect is difficult to quantify, but reduced flows are expected to limit erosion and pollutant transport.

The direct effect on water quality depends on the type of swale. Studies in Florida found residential swales which drain into a sewer or surface water system providing only partial infiltration differed from swale/percolation where nearly all the runoff is infiltrated. The following table presents the actual values found during a study in Orange County, Florida (Lynard et al., 1980):

	Residential swale (percent removal)	Swale/Percolation (percent removal)
BOD_5	38	93
TN	16	90
TP	0	92
TSS	89	96

Planning Considerations

Grass lined swales are best used as an alternative to paved channels. Swales permit water to seep into the ground, while grass provides filtering, erosion and velocity control benefits that other surfaces do not. Swales also provide a way to collect runoff for infiltration and discharge. Grassed swales can be used along roadsides to replace conventional curb and gutter installations or applied as a drainageway alternative. When underdrains are applied swales are often constructed to direct water into the system. Grass lined swales are considered to be an aesthetically pleasing method of controlling periodic runoff.

Design Considerations

Swale installation costs are not large, since their construction can be scheduled as part of the final site grading. Excavation and seeding or sodding costs should be included when calculating the initial cost. A study in Orange County, Florida found the capital cost was $3,945/acre for a swale/percolation measure and $2,539/acre for a residential swale (Lynard et al., 1980).

O & M costs will depend on the complexity of the swale, though if built properly a swale is very inexpensive and durable. A residential swale will need landscape care, debris removal and runoff damage repair, while a percolation swale would require more expensive maintenance, including sediment removal and vector and insect control. The Orange County study estimated annual residential swale O & M costs to be $97/acre while swale/percolation O & M costs were $612/acre.

Swales are not difficult to develop and use if they are properly planned and constructed. They should be designed to control runoff from frequent storm events and to dispose of overflow in a non-erosive manner before the capacity has been exceeded. Site slopes should not be designed so steep as to promote erosion and flow velocities should be controlled through grade and outlet design. Swales designed to percolate runoff should also consider the hazards of standing water, insect breeding grounds and vegetation damage in their design.

INFILTRATION TRENCH

Description and Purpose

An infiltration trench is an excavated ditch that is filled with sand or gravel (Figure 16). The purpose of this ditch is to reduce stormwater runoff by promoting percolation. Surface water quality is improved through reduced erosion caused by high runoff volumes and filtering of contaminants during percolation.

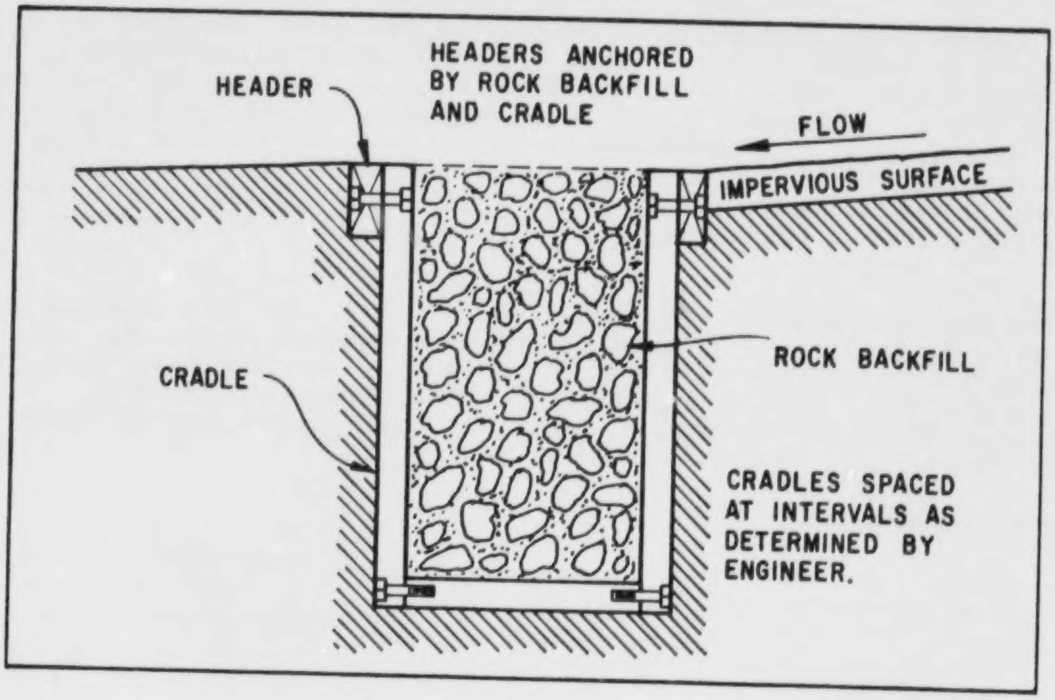

HEADERS ANCHORED BY ROCK BACKFILL AND CRADLE
HEADER
FLOW
IMPERVIOUS SURFACE
ROCK BACKFILL
CRADLE
CRADLES SPACED AT INTERVALS AS DETERMINED BY ENGINEER.

Figure 16. Infiltration Trench Designed for Percolation of Runoff. Source: White and Franks, 1978.

Target Applications

Infiltration trenches are aimed at reducing water quantity, though suspended particulates are removed as a water quality benefit. Infiltration ditches are usually applied when runoff from impervious surfaces must be reduced. They provide detention and infiltration for runoff directed from impervious surfaces. Infiltration trenches should not be applied when soils have low permeability since seepage will be inadequate; when groundwater pollution will result from contaminents transported with the increased percolation; and when runoff is highly sediment-laden since clogging will result.

Effectiveness

The effectiveness will vary with the soil type, that is, highly permeable soils will be more effective than soils with low permeability. Trenches capable of retaining and infiltrating 100 percent of the runoff volume will provide 100 percent effectiveness at keeping drainage area pollutants from entering surface waterways. Trenches capable of retaining only part of the runoff volume will be less effective, but they can still benefit water quality by filtering and settling runoff pollutants, as well as aid in reduced degradation of downstream channels by reducing flow volumes and corresponding erosive forces.

Planning Considerations

Infiltration trenches are best applied on highly permeable soils. The trench increases the infiltration rate by providing sump storage and a porous medium to filter runoff.

Infiltration trenches are best used in situations where impervious surfaces create an increase in runoff volume. Trenches can be placed in parking lots to reduce runoff. Dutch drains are gravel filled ditches which may have a drainage pipe at the bottom. Dutch drains are used to collect runoff from roofs without gutters. The ditches may be left as bare gravel or with a layer of vegetation. Grasses, shrubs or trees, planted on the ditches reduce runoff through evapotranspiration as well as infiltration and provide an aesthetically pleasing cover. The trenches can also be paved with porous pavement to allow traffic crossing.

The final design of infiltration trenches should be done by a qualified engineer. Design factors that should be considered include trench area, area of contributing impervious surface, soil percolation rate and design storm (duration, amount). Overflow provisions should be designed for the ditch. Circumstances where overflow might occur include runoff greater than the design storm or clogging from deposited sediments.

Design Considerations

For ease of use trenches must be properly designed. The infiltration trenches must be designed to either handle the total runoff flow, therefore, eliminating the need for a storm drain system or designed to infiltrate part of the flow, which reduces the required size of the drainage system. In either case a substantial cost savings over the conventional drainage system will partially pay the installation costs.

The quality of water entering infiltration trenches should be considered when designing them. High levels of sediments will clog the surface or subsurface area reducing infiltration capacity. To increase the active lifespan of an infiltration trench, sediment traps can be employed. Drop inlets, porous paving, or gravel and grass coverings can be used to remove sediments. Oil and grease should be separated from runoff before it enters the trench since these contaminants are difficult to remove with traditional cleaning operations. Even with devices to remove some pollutants, trenches will need periodic cleaning to retain the infiltration rates. Infiltration trenches should not only be constructed to prevent high sediment loadings, but to provide an ease of maintenance.

Infiltration trenches are structural measures that store and infiltrate runoff water. They are least expensive when constructed while the impermeable surface they are meant to serve is installed. Costs are estimated for a Dutch drain at $52/cubic yard water stored and for a gravel trench at $41/cubic yard water stored (Stanley Consultants, 1976).

O & M needs include cleaning out sediment built up in the trench. In most cases this involves removing the rock backfill and either washing and reusing it or replacing with new rock. This can be a fairly expensive procedure, which encourages the application of sediment barriers to reduce the maintenance costs. Other O & M needs include surface debris removal and landscape care.

SUBSURFACE DRAIN

Description and Purpose

A subsurface drain is a perforated pipe installed beneath the ground to collect and convey drainage water. Subsurface drains remove shallow groundwater and percolated surface water. Inlets to the subsurface drain can be through natural seepage or through a structural inlet (Figure 17). The purposes of installing a subsurface drain are to:

- Drain surface water, runoff and detention areas;
- Improve vegetation by lowering the groundwater table;
- Serve as an outlet for other drains; and
- Replace natural subsurface drainage patterns which are interrupted due to construction operations

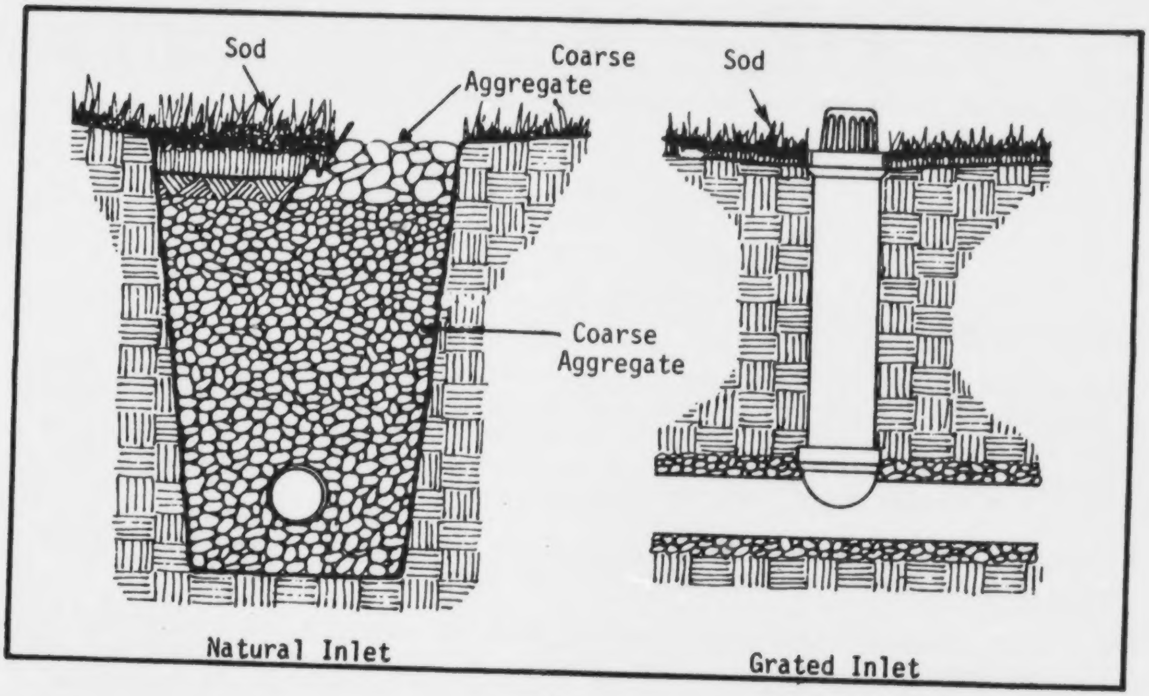


Figure 17. Inlets to Subsurface Drains.
Source: Virginia SWCC, 1980.

Drains are applied to remove either surface water or groundwater. Drains intended to remove surface water achieve a slight water quality improvement due to increased percolation. In some cases additional filters are installed to increase sediment removal and keep sediments from plugging the drainage pipe.

Target Applications

Subsurface drains are designed to reduce water quantity problems, though water quality benefits may result such as the reduction of waterborne sediments. Subsurface drains are only applied when site factors combine to make this expensive MP economically feasible. It is applied when the water table is high enough to disturb the land areas intended use or when infiltration of runoff is desired. The soil type and depth must be adequate to allow system installation and it must be permeable enough so that the benefits obtained justify the installation cost.

Effectiveness

A Florida study (Lynard et al., 1980) found that a perforated pipe in gravel providing drainage under a swale had a relatively high efficiency in reducing the pollutant loading from stormwater runoff. This study achieved 100 percent flow reduction, but in most cases flow reductions will be substantially lower. With all of the runoff filtering down to the underdrain, measurements at the drain outlet found the following pollutant removal percentages:

BOD_5	96 percent
TN	54 percent
TP	93 percent
TSS	99 percent

Planning Considerations

Subsurface drains are best used to combat an excess quantity of water. Since these drains are underground, the surface can be designed as desired. Often the surfaces are sodded making this an aesthetically pleasing solution. The conduit should be designed according to required capacity, topography, soil type, groundwater conditions and land use.

Conduit features that can be manipulated according to the site needs include materials, placement, grade, velocity, and inlet and outlet size.

- Drain materials should be chosen to meet the strength and durability requirements of the site. For instance drainage lines subjected to heavy vehicle traffic might be made of concrete for durability. A variety of materials may be applied as a foundation for the drain. To improve the flow into a drain it is usually surrounded by aggregate. Drains that are subjected to high concentrations of silt or fine sands will require sediment barriers to prevent the washing of silt into the gravel voids and clogging of the system. Commonly used materials include permeable layers (such as straw) between the soil and gravel, filter fabric, or drop inlets.
- Drain placement including location, spacing and depth should be designed to provide the best service for the purpose of the drain. Subsurface drains should be located way from trees since roots will damage or clog a subsurface drainage system.
- The pipe must be graded to keep water flowing in the correct direction and the flow velocity within recommended limits. In cases where there are gradient deficiencies pumping can compensate, though the system cost will increase.

- The velocity should be designed within a minimum level to prevent sedimentation inside the drain and within a maximum level to prevent pipe and outlet degradation.
- The pipe size (diameter, length) should be designed to meet all of the capacity requirements.
- The inlet should be designed to avoid sediment or debris build up. Inlets can have grassed or gravel swales or some other type of drop structure.
- The outlet should be designed to dispose of the discharge without damage around the point of discharge.

Design Considerations

Subsurface drains can be expensive to install. Installation includes excavating a trench, laying the pipe and usually filling the surrounding area with gravel, possibly including sediment control devices and grading to direct surface water to the drain area. In a Florida study the installation cost of an underdrain system was $3,440/acre (Lynard et al., 1980).

O & M needs are limited. Subsurface drains should be periodically inspected to insure that the pipe is free flowing. Clogging due to sediments, structural damage or tree roots should be repaired immediately. Under most circumstances clogging will not occur in which case O & M costs will be low, consisting only of outlet and inlet cleaning.

PERVIOUS DETENTION FACILITY

DESCRIPTION AND PURPOSE

Pervious detention facilities are areas where stormwater is detained until it can be percolated through the soil. The three basic forms of percolation detention are basins, pits and seepage areas. Basins are the most commonly used detention facility. Infiltration basins are excavated ponds on pervious soils. Seepage pits or "dry wells" are excavatd areas that are filled with gravel or sand. They are similar to infiltration trenches but do not conduct runoff along their length. A seepage area is low lying land onto which runoff is channeled for infiltration.

The purpose of applying pervious detention facilities is to control stormwater runoff and recharge groundwater. Stormwater runoff is diverted to an infiltration area thus reducing discharge to surface water systems. Surface water pollutants are also reduced since contaminants carried by the diverted runoff are not delivered to the waterway and the reduction in discharge volume prevents erosive forces of high waste levels from degrading the waterway. As urbanization occurs, increases in impervious surfaces disturb the natural recharging of groundwater. Percolation detention facilities provide a method to keep infiltration at its predevelopment levels.

TARGET APPLICATIONS

Infiltration detention is aimed at water quantity control. This method reduces the delivery of pollutants to surface waters by percolating the runoff. Caution, however, must be exercised so that levels of pollutants are not substantially increased in shallow groundwater.

Percolation detention facilities can be applied when areas are being developed or after development to handle increased runoff. Urbanizing areas increase the percentage of impervious land areas which increase runoff quantities and decrease groundwater recharge. They are usually applied in aquifer recharge areas, but can be used whenever the water table is permanently below the facility´s base. Percolation detention facilities are easiest to install in urbanizing areas during development. Installation costs can be cut if the facility is designed as part of the site construction. Fully urbanized areas are less likely to have the available land required for this permanent facility, but infiltration is one option for urban area runoff treatment. However, developed urban areas have higher levels of contaminents in the runoff, which because of the danger to groundwater limits the use of percolation as a MP method.

Pervious detention should only be applied when soil permeability is sufficient to infiltrate the runoff at a reasonable rate. If the percolating capacity of the soil is inadequate to meet the runoff rate this method should not be applied. As soil infiltration rates decrease, larger land areas are required until this MP becomes uneconomical and impractical. Infiltrating water can transport pollutants into the groundwater, particularly in situations such as basins and pits where excavation allows runoff to bypass filtering soil layers. Before applying this MP an analysis of the increase of pollutants in the groundwater and its intended use should be completed to determine if this MP should be used. Periodic monitoring should be done to assure that contamination of groundwater is not occurring.

EFFECTIVENESS

Pervious detention facilities are effective at keeping pollutants from entering surface waterways, as well as reducing runoff quantities. These pervious detention facilities can be up to 100 percent effective at reducing surface pollutants if all the runoff is captured and percolated into the soil.

PLANNING CONSIDERATIONS

A qualified engineer is generally required to design detention facilities. To provide the best application the facility must be properly designed. The design must take into account watershed and site factors. Watershed factors will determine the amount of runoff that will discharge into the detention facility. These factors include design storm (frequency, duration, intensity), drainage area, topography and runoff percentages. Site factors, soil permeability and topography direct the requirements of the detention design. Volume factors can be manipulated to change the capacity and filtration area.

The location of the facility should be choosen to provide the least expensive alternative. Most storage facilities are constructed on-site. On-site storage cuts down the distance runoff must flow over urban surfaces or other pollutant sources. On-site facilities can be smaller and usually have cheaper installation costs, though they usually are more expensive to maintain. The best location for a percolating detention facility is a natural or previously excavated depression, or low lying area. They require less construction in excavation, embankment and runoff diverting systems. Possible depressions may be a gravel pit, a fill source or a wetland.

Depending on the water table level, wetlands may provide an excellent natural infiltration area. If the water table is lower than the soil surface, runoff infiltrates into the groundwater. Even if no infiltration occurs evapotranspiration can reduce the total outflow volume. Facilities must be designed for a chosen runoff flow. It is considered more economical to design the facility for normal runoff volumes and provide overflow alternatives for disposing of runoff from extremely heavy storm events. The cost of an emergency spillway for a basin or an overflow system for a pit will be recovered by the decrease in required storage volume.

When possible, pervious detention facilities should be designed for multipurpose use. Proper design will reduce objections of detention as a neighboring land use. For instance, a seepage area can be grassed and used as a park or open space. When covered with porous pavement it doubles as a recreational area, or parking lot. The only requirement is that the alternative use does not overlap with the time needed to percolate runoff. Permanently filled basins can be incorporated as part of a park or landscaped area. Cases where multi-purpose or aesthetically pleasing detention facilities are impractical can be separated from the public with sight barriers such as trees.

The best use of a basin as an infiltration detention facility is determined by considering several factors. Basins can be designed to retain runoff at shallow or deep levels. The deeper levels are capable of recharging more water since they operate under a greater head. Therefore, deeper basins require less land area. Because basins are excavated they take less advantage of the filtering effect of the soil. Seepage basins have other disadvantages in that they tend to be unattractive and require intensive management to maintain the original infiltration rate.

Dry wells are best used to control stormwater runoff from impervious surfaces such as parking lots, building roof or lawn area. Dry wells require less space than other facilities, but have the negative effect of bypassing soil layers which could infiltrate contaminants. The pits are also susceptible to clogging and are difficult to clean. Dry wells require a supplementary system to accommodate overflows. Their design is similar to that of infiltration trenches.

Seepage areas are shallow basins or low lying areas that can be designed to be filled with water only part of the time. They are best suited for applications as multipurpose facilities. The areas can double as recreational areas, parking or open space areas. Large land area requirements and the need for extremely fast infiltration rates limit the use of seepage areas. When used as a multipurpose facility, the area may require design modifications and additional maintenance expenditures to keep the area publically acceptable.

The positive effects are that runoff is filtered through all of the soil layers which decreases the danger of contaminants being transported to the groundwater. Seepage areas are often covered with either grass or porous pavement. Grass covered surfaces provide additional pollutant filtering which should improve the quality of the recharge water. It also is considered an aesthetically pleasing surface. Porous paving is one of the easiest surfaces to clean, and can be used for many alternative purposes, although the Minnesota climate limits the applicability of most porous pavements (see next section on porous pavement).

An alternative detention method is instream storage. Any device which retains water in contact with a pervious surface can enhance runoff infiltration. The only prerequisite is that the soil be adequately permeable. Typical devices include check dams and diversions, but these rarely infiltrate quantities worth evaluating.

DESIGN CONSIDERATIONS

The installation costs of pervious detention facilities will depend on the natural features of the proposed site, the soil permeability and facility design. Percolation costs may be cheaper if they are constructed in low lying areas (wetlands) or previously excavated areas (gravel pits, fill source) since they will require less excavation, embankment and spillway work. Poorly drained soils require higher capital costs to achieve the same infiltration efficiencies.

Land costs are rarely included in the installation cost, but should be considered when making a cost analysis to determine economic feasibility. The order of increasing land requirements, that is, pits, basins, seepage areas is also the order of decreasing installation costs. A previous Metropolitan Council study found infiltration oriented detention facilities cost between $1,000-$5,000/acre in urbanized areas. The most expensive site was downtown Minneapolis, though most sites where not in fully developed areas and were, therefore, much cheaper (Oberts, 1982). Other reported costs (Lynard et al., 1980) are as follows:

	Costs of Percolation Ponds
Initial*	$2,400-4,670/watershed acre $8-20 cubic yards water stored
O & M	$400-800/watershed acre

* Land costs not included.

It is important to fulfill the O&M needs to keep an infiltration detention facility percolating properly. Maintenance requirements include debris removal, sediment removal, landscape upkeep, erosion damage repair, vector and insect control and vegetation control. The major concern for all infiltration facilities is clogging. Unless infiltration areas are properly maintained sediments will clog the bottom reducing the percolating effect of the facility. To prevent clogging, the water discharged into the infiltration area can be filtered, or runoff with extremely high sediment loads diverted to a sedimentation control structure. Once an infiltration facility experiences a significant reduction in permeability, maintenance is required.

Basin soils may be tilled or in extreme cases seepage holes or pits dug in the basin base. Seepage pits must be cleaned in the same manner as infiltration trenches. The most difficult facility to maintain is the multi-purpose seepage area, unless it is covered with porous paving. Unfortunately, these multi-purpose areas require the most upkeep since the area not only must remain unclogged for infiltration, but aesthetically pleasing if used by the public.

The maintenance of a detention/percolation facility can be the responsibility of the developer, for instance the O & M needs for facilities built in connection with a highway project should be met by the Department of Transportation. Generally the maintenance activities, however, usually become the responsibility of local government, a homeowners association or a property management organization.

Unfortunately, infiltration areas are often left inadequately maintained. Particularly small facilities created by private developers, therefore maintenance measures should be considered and planned as part of the original design. To assure that maintenance is carried out, ownership and operation should be encouraged as a public responsibility or local public agencies should be given the authority to maintain infiltration detention facilities that are privately owned and charge a fee to the development for reimbursement.

POROUS PAVEMENT

DESCRIPTION AND PURPOSE

Porous pavement is constructed to provide a firm, stable surface for transportation while allowing water to infiltrate. Porous pavement can be constructed from a porous substance such as asphalt on top of a coarse gravel base. It can also be made as a lattice pavement of bricks or concrete grids, where filtration areas occur within the pavement structure (Figure 18). The purpose of porous pavement is to control runoff quantities by increasing infiltration through traditionally impervious surfaces. Land uses where the MP may be applied include highways, streets, sidewalks, driveways, parking lots and playgrounds.

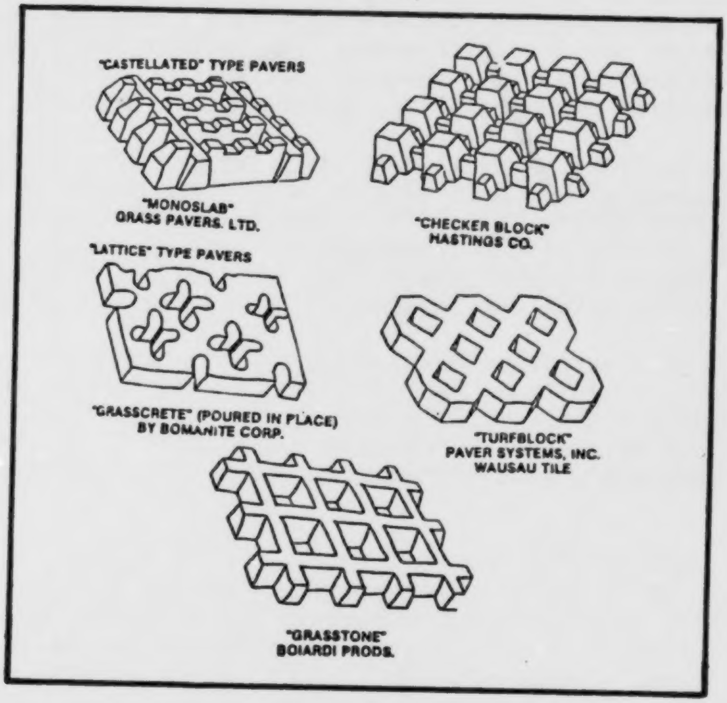


Figure 18. Various Types of Lattice Pavements.
Source: Field et al. 1982.

Porous pavement retains runoff by providing water detention in the base and pavement and percolation through the soil which may replenish groundwater supplies. By reducing runoff volumes, porous pavement holds back peak stormwater surges and reduces the discharge rate. This minimizes flooding and streambank and soil degradation due to high runoff volumes, resulting in a reduction of pollution loadings due to erosion. It also eliminates sewer overflow and the need for an expensive conventional drainage system.

TARGET APPLICATIONS

Pervious paving is aimed at reducing the pollutants which result from high runoff volumes. Porous pavement should be used when an impervious surface would interrupt natural drainage patterns and result in destructively high levels of runoff. Since replacing existing surfaces is excessively costly, porous pavement should only be applied as a new surface or incorporated into planned reconstruction.

Porous pavement should be used only when local factors will sustain the design. Local factors include topography, temperature, soil type and groundwater. Minnesota has exteme temperature variations which generally limit porous pavement applications, though conflicting reports on the durability of permeable surfaces during freeze-thaw cycles have not been resolved (Field et al., 1982).

EFFECTIVENESS

The emphasis of porous pavement is the reduction of water quantity. By reducing runoff quantity benefits to water quality are expected. Direct water quality effects are still being studied, but have not been measured. Runoff reduction varies with the type of pavement, but volumes may reduced up to 85 percent (Oberts, 1980). Grid pavements will provide higher reductions than asphalt pavement.

Studies of the direct effect on water quality indicate some improvement. Porous pavement can be designed to act as a detention pond and while effectively delaying runoff and dampening peaks it removes some pollution materials. A parking lot study in "The Woodlands" testing conventional against porous pavement with an underdrain found organics and nitrates were lowered though ammonia levels rose, suggesting anaerobic decay. Lead and zinc levels were also reduced slightly (Lynard et al., 1980).

PLANNING CONSIDERATIONS

To provide the best use pavement design and materials must be durable enough to sustain the design use under local conditions. By manipulating the materials' pore size and percentage voids, infiltration capacity can be varied. The design can be changed to accommodate site requirements. Changes in design include base and surface thickness, additional drainage features, surface gradient and in the case of lattice pavement, shape. The intended use of a paved surface will dictate the design requirements. For instance, lattice pavement should only be used in low traffic areas. They provide poor walking surfaces and are expensive and difficult to construct, all factors which discourage use. Some pavements become pulverized from heavy traffic use. Lattice pavement is most often used in landscaping.

Local factors, such as topography, weather, soil type and groundwater must be considered before designing a porous surface.

- Topography will vary the pavement grade, and runoff volume on to the surface, changing the infiltration capacity requirements.
- Weather creates additional wear on the pavement. Freeze-thaw cycles may destroy pavements, particularly asphalt over a gravel base. The use of porous pavements may be restricted if infiltration capacity is less than runoff volume.

- Soil must be permeable enough to allow adequate infiltration for drainage without ponding. Lattice pavement can only be used where natural drainage is fast, while asphalt pavements can be used on less permeable soils by applying additional base material for increased water storage.

- Groundwater may be replenished since infiltration is promoted, therefore, if any possibility exists of groundwater contamination, porous pavemets should not be used.

Porous pavements have had limited experimental applications. Currently, many areas have permit regulations requiring the construction of standard sized storm drains. Until porous pavements are proven to be capable of disposing of runoff, regulations are not likely to be revised. Since the economic advantage of asphalt pavements rests on the reduction or elimination of conventional drainage systems and the climatic factors in Minnesota are questionable for the application of porous pavement, the use of porous pavements here is likely to remain limited.

Porous asphalt paving can be used to increase traffic safety, by preventing standing water. Incidents of vehicle hydroplaning are reduced and puddles do not disturb pedestrian traffic. In northern climates where some porous pavements degrade speedily, asphalt is applied over normal concrete pavement to prevent hydroplaning.

DESIGN CONSIDERATIONS

Porous pavements are more expensive, but do not require the drainage system needed by conventional pavement. Cost savings from eliminating curbs and gutters and reducing storm sewers requirements may make porous pavement cheaper than conventional pavements. Comparing materials costs, lattice pavements such as castellated or pervious grids are the most expensive, while in most cases porous asphalt pavement will be cheaper than a conventional pavement with a storm sewer drainage system (Stanley Consultants, 1976). Cost differences may vary by site. Conventional concrete pavement remains the most economical for use on large areas such as parking lots and playgrounds. The following figures compare conventional and porous pavements (Oberts, 1980):

Type of Use	Conventional Pavement With Drainage	Porous Pavement
Parking lot	$10.79/sq.yd.	$14.51/sq.yd.
Residential street		
Low design	$16.43	14.49
High design	$23.34	14.56
Business street		
Suburban	$19.17	$14.56
City	$41.53	$17.48
County Road	$20.99	$14.69
Highway		
Two-lane	$33.09	$16.79
Four-lane (asphalt)	$54.49	$19.35
Four-lane (concrete)	$58.94	$19.71
Playground	$10.38	$14.47

O & M is important to retain the initial benefits supplied by using porous pavement. Considering that conventional pavement will require O & M expenditures, substituting porous pavement would only require a slight increase in expenditures. One difficulty that arises during use is that porous pavements are susceptible to clogging. Unless the pavement is cleaned with a vacuum sweeper or high pressure washing, permeability will decrease with time. Cleaning maintenance requirements may be reduced if erosion and sediment controls are applied to keep dirt and other clogging materials from the pavement surface.

The ease with which porous pavements are developed and used is closely related to climate. In northern climates special design specifications are being studied to combat freeze-thaw cycle degradation. The control of snowmelt runoff may require the addition of curb and drainage systems, reducing the economic advantage of using porous asphalt pavement.

ENERGY DISSIPATION

ROUGH SURFACE

DESCRIPTION AND PURPOSE

To dissipate energy, either over land or in-channel, runoff can be directed over a rough, stabilized surface. The friction of flowing over a rough surface reduces the flow forces and their erosive power. It is important that the surface over which the water the is discharged is sufficiently stabilized to prevent erosion and is free of pollutants other than soil.

Stabilized rough surfaces that are commonly used to dissipate excess flow energy include vegetation, erosion control mats, scoured surfaces and riprap in channels. These erosion control measures actually prevent erosion in two ways, by stabilizing the soil surface and by dissipating excess energy. (See the appropriate sections under erosion control).

LEVEL SPREADER

DESCRIPTION AND PURPOSE

A level spreader is an excavated depression constructed at zero grade across a slope. It is used as an outlet that converts concentrated runoff to a sheet flow which is released to a stabilized vegetated area at nonerosive velocities. The purpose of constructing a level spreader is to dissipate energy by widely spreading flow and distributing it over a coarse vegetated area. Level spreaders utilize the energy dissipating ability of vegetation to reduce flow forces.

TARGET APPLICATIONS

The targets are sediments caused by erosion and the associated pollutants. Level spreaders reduce erosion by dissipating the erosive force of concentrated flow. Level spreaders are used where severe gullying from concentrated flow is a potential problem. They are most often applied as outlets for runoff diversions. Level spreaders should only be used when they can be constructed on undisturbed soil and when the area below the spreader lip is well stabilized with established vegetation. They should not be used when runoff is laden with sediment or when excess water could damage the level spreader discharge area.

EFFECTIVENESS

When properly applied a level spreader effectively reduces runoff velocity and erosion. Erosion control has been reported between 50-60 percent effective (Oberts, 1981). A reduction in erosion would be expected to have a positive effect on water quality through reduced sediment and associated loadings.

PLANNING CONSIDERATIONS

For the best results a level spreader should not be used to handle sediment-laden runoff; not be placed on a fill; or discharge sheet flow to an unstable area. Sediment-laden runoff may result in sediment accumulation in the level spreader channel or on the discharge area. Discharging to unstable or fill slopes may result in increased erosion of these areas.

The level spreader specifications, length, width and depth should be designed to accommodate the design flow. The entrance to the spreader should be constructed to assure that all the runoff enters the channel, but the slope leading directly to the entrance should be graded to not exceed a one percent gradient (Virginia SWCC, 1980). The grade of the level spreader must be zero, and the discharge lip must be uniform height at a zero grade.

DESIGN CONSIDERATION

A level spreader is not difficult to develop or use. It can easily be installed as part of the preliminary construction site preparation. Difficulties may occur if it is not properly installed or maintained. Unless the spreader is constructed according to the design criteria, erosion and outlet failure may occur. For instance an uneven discharge lip will allow concentrated flow to occur below the outlet, resulting perhaps in outlet failure. When using a level spreader, flow should not reconcentrate after release from the structure.

Level spreaders tend to be moderately inexpensive. Initial costs may vary between $3.10 - 8.70 per foot (Oberts, 1980). Costs vary with length, the shorter level spreader will have a more expensive unit cost than the longer one. Regular maintenance is essential for the operation of a level spreader. O & M needs can be met by the contractor and treated as part of a site's construction activities. A level spreader should be inspected after significant rainfalls and repairs made as required. On a construction site, damage caused by traffic or other activities should be repaired immediately.

GRADE STABILIZATION STRUCTURE

DESCRIPTION AND PURPOSE

A grade stabilization structure is designed to convey concentrated flow from one elevation to a lower elevation. The purpose of these structures is to prevent gullying and erosion caused by energy increases from flowing down gradient. There are two structural methods of stabilizing a channel gradient. Conveyance methods, such as flumes and slope drains (see previous sections) provide a structure in which highly erosive flow can be harmlessly transported down a gradient. Erosion is prevented by reducing the contact between flow and the erodible soil. Drop structures reduce the gradient of the channel by introducing controlled vertical drops to compensate for the elevation drop (Figure 19). They prevent erosion by dissipating energy and lowering the flow velocity. Typical drop structures include drop boxes, checkdams or stabilized falls.

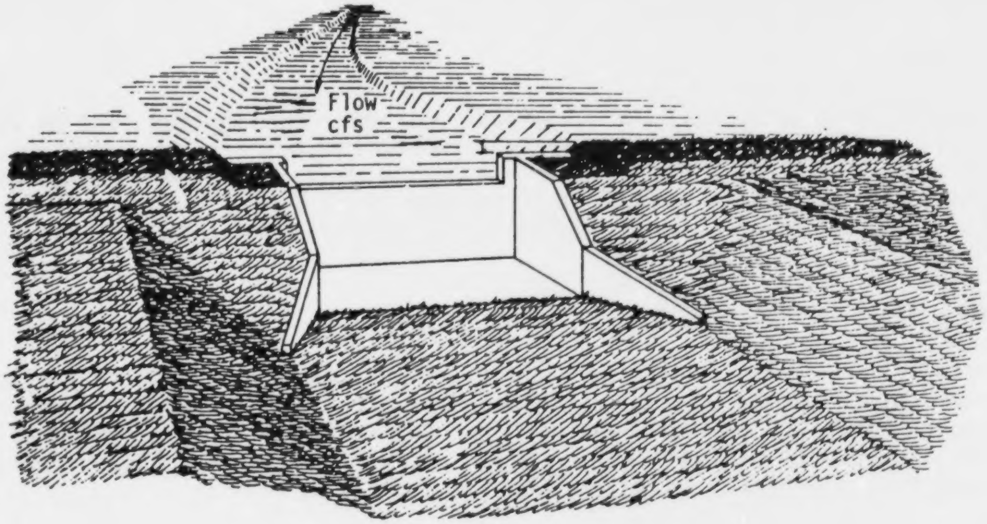


Figure 19. Waterway Drop Structure.
Source: Virginia SWCC, 1980.

TARGET APPLICATIONS

Grade stabilization structures are aimed at controlling erosive situations. The structures may be applied when concentrated runoff flowing down a gradient may cause gullying or down cutting. These structures are generally applied in sloping channels, but may also be used as outlets for detention facilities.

Flumes are used when a slope requires a short channel to convey water without erosion. Concrete flumes are applied when a cut or fill slope needs permanent protection. Flumes from less durable materials, or slope drains are applied as temporary measures to protect slopes during construction activities, particularly highway projects.

Spillways are applied when detention facilities need an outlet that will convey water over a gradient in a controlled manner. Spillways discharge outflow at super critical velocities and should not be used without energy dissipators at the base.

Drop structures are used when the runoff velocity of a drainageway must be reduced to reduce erosion. They can be constructed as either permanent or temporary installations. Drop structures are used when runoff must travel down a long steep slope without a significant increase in flow velocity or when construction activities are expected to increase erosion problems.

Grade stabilization structures should not be constructed until the drainage area has been protected from erosion since high sedimentation loads may shorten the intended lifespan of the structure, particularly permanent installations. They should not be used as a sediment reduction method , although temporary ponding will yield some solids removal. They should not be applied when flooding caused by temporary detention behind the structure would cause property damage, or when the placement of the structure in a permanent waterway will cause severe aquatic degradation.

EFFECTIVENESS

Grade stabilization structures provide indirect water quality benefits by reducing channel erosion, but they are rarely directly responsible for removing existing pollutants. These structures reduce sediment loading by dissipating the erosive forces and conveying runoff through stabilized channels. Grade stabilization structures may reduce TSS in the range of 50 percent (Oberts, 1981).

PLANNING CONSIDERATIONS

Grade stabilization structrues are best used when physical conditions are to severe for establishment of vegetative cover or other nonstructural measures. Each type of structure is best applied under different conditions. Generally spillways are used as outlets for detention facilities, flumes on short steep slopes and drop structures on long steep slopes.

Dissipating materials are used to control high velocity or turbulent flows discharged from grade stabilization structures. Dissipators are placed at the base of a structure to prevent undercutting of the structure or erosion around or below the outlet. These dissipators are structural additions in the form of concrete blocks, anchored rip rap or outlet toe shape that create a roughened stabilized surface that will reduce flow velocities by absorbing energy. Energy dissipating devices are required for flumes and spillways which release flow at highly erosive velocities and are recommended for drop structures which may have turbulance at the outlet.

Grade stabilization structures should be designed and applied according to specific design specifications. Since the permanent structures are often expensive and have significant effects on water levels and adjacent land the design should be done by a qualified engineer. Temporary structures are usually used with construction and can be designed as part of the construction plans. The structural design will depend on the drainage area size, site characteristics and capacity requirements. Design specifications should include dimensions (inlet, structure, outlet), foundation, channel alignment, materials and stabilization of the surrounding area.

DESIGN CONSIDERATIONS

A difficulty encountered during construction is the acceleration of erosion and sedimentaton rates. During the construction process soil disturbances and activities will temporarily create heavy runoff loading and may require applications of additional erosion control MPs. Other construction difficulties may result from improper placement, use or installation.

The cost of grade stabilization varys greatly depending on the structural design. Temporary measures are less expensive then permanent measures. Generally the price increases with size, complexity and durability. The following examples show comparisons between types of structures (Virginia SWCC, 1980):

Structure	Cost
Temporary flexible slope drain	$2.47-5.60 per foot
Permanent asphalt paved flume	$2.75-4.12 per square foot
Permanent concrete drop structure	$2.75-4.12 per cubic foot

After construction the installation should be inspected for scouring, soil settling, structural faults and bank vegetation establishment. For permanent structures once the surrounding area is stabilized minimal maintenance is required. Temporary structures require periodic inspection to assure construction site activities and heavy sediment loaded runoff have not damaged the installation.

CHECK DAM

DESCRIPTION AND PURPOSE

A check dam is a barrier of stone, wood, steel, earth or concrete constructed across small man-made or natural channels as a grade stabilization structure (Figure 20). The purpose is to lower the velocity of concentrated flows by dissipating energy. The lower flow velocity primarily acts to reduce the erosive forces on the channel while providing a secondary benefit of trapping small amounts of sediment.

TARGET APPLICATIONS

Check dams are aimed at preventing solids from polluting surface water by reducing erosion and trapping solids. Check dams are applied when sediment laden flows are a problem. They are applied as temporary measures on construction sites though with additional grading and revised construction the design specifications for check dams can be adapted as permanent measures.

As a temporary measure check dams are applied when permanent stabilization is infeasible or unwanted. They are used to provide protection until a vegetative lining is established. Check dams are used in temporary waterways that have no lining because of their short lifespan, or in permanent waterways where the placement of a nonerodible lining is delayed.

EFFECTIVENESS

Check dams are grade stabilization structures used as preventive measures to reduce channel erosion and prevent further degradation of water quality. As an erosion control method check dams have been reported to be 50-60 percent effective (Oberts 1981). Though check dams are meant to reduce erosion they will trap sediments and therefore have some capacity to improve water quality. When properly applied and maintained check dams have been reported as obtaining 40-90 percent trapped solids (Stanley Consultants, 1976).

PLANNING CONSIDERATIONS

Temporary check dams are best applied where they do not need to be visually pleasing, or need to be constructed and designed to provide long-term use. The removal of a check dam should be considered as part of the use plan. Removal may represent a significant cost as well as create additional soil disturbances. Temporary check dams are removed once the area they are protecting is stabilized. To reduce the silt disturbance created during removal, the area should be permanently stabilized immediately. While removing stone check dams create less of a soil disturbance than embedded dams, such as log dams, additional care must be taken to remove all stones, including those washed downstream.

Check dams used as permanent installations require additional design and construction considerations. A check dam which will be a permanent structure requires the use of durable materials such as concrete or steel. Sheet piling creates a permanent waterway structure that handles large discharges. These steel check dams are constructed by driving piling into the ground to a depth between two to three times the height above ground. Riprap is required around the check dam for protection against erosion. The advantages of using sheet

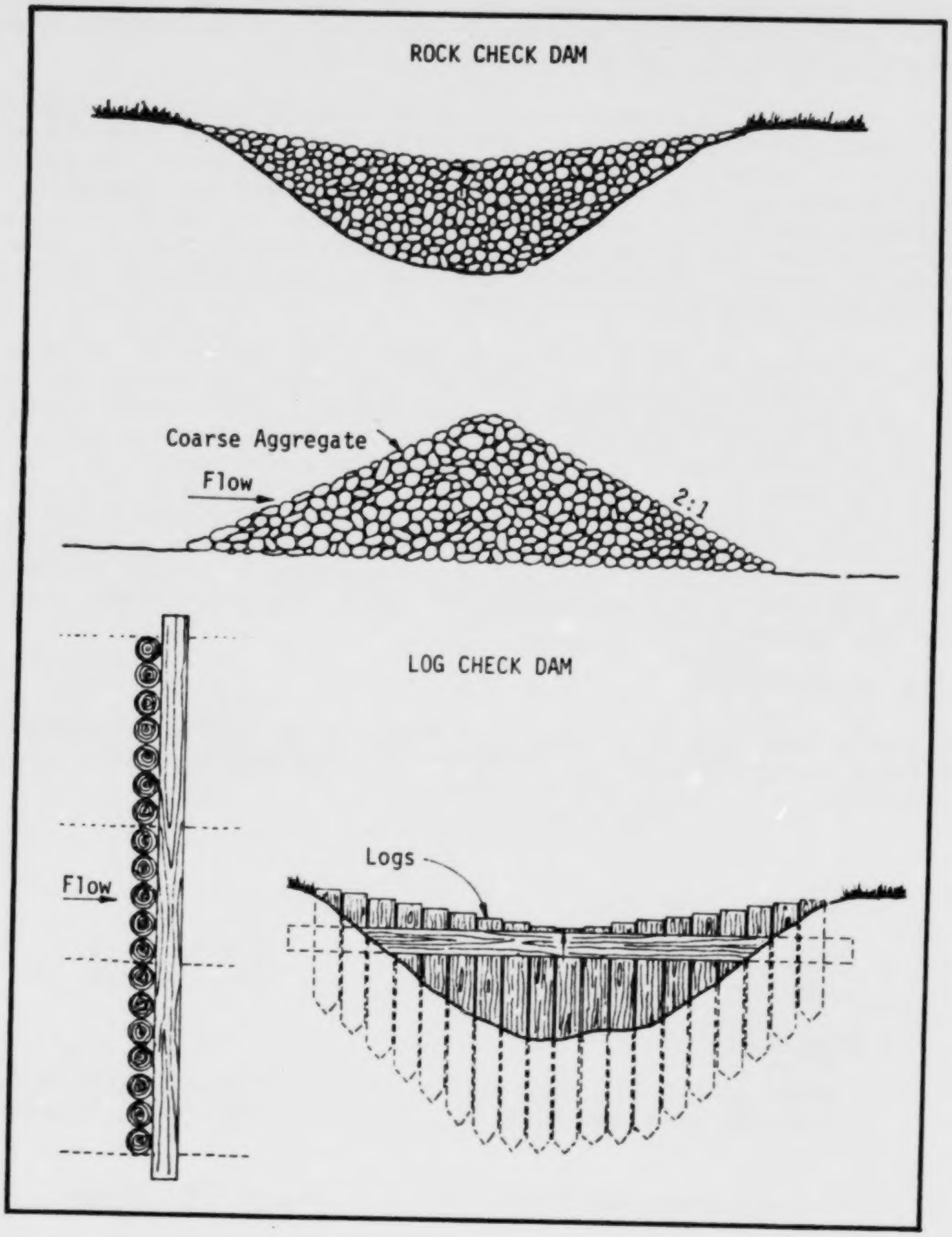


Figure 20. Examples of Check Dams.
Source: Virginia SWCC, 1980.

piling include that it can be installed in moving water. This means that diversions and dewatering are not necessary. Since sheet piling requires minimal grading and clearing, it is valuable in areas that are inaccessible or where the least possible disruption is desired.

Concrete check dams are best used when dissipating the energy of large flows will reduce streambank erosion. Construction of a concrete check dam requires temporary diversion of water away from the construction site. Excavation is needed to provide a base and since the hole must remain dry, dewatering is necessary. Specific construction procedures include the use of forms and for large structures pouring in stages. This process usually requires large amounts of clearing and grading which disrupts a large area that should be restored when construction is completed.

Check dams should be able to handle the design flow and can be varied by manipulating the design considerations, height, cross section, spacing and anchoring. To prevent gullying around the check dam or dam failure the channel at the dam site must be completely covered and the dam, anchored, braced, connected and constructed with materials capable of withstanding high flow velocities. No formal design is required to construct a temporary check dam though a few criteria should be met. Permanent check dams do require formal planning and designing. The application of a check dam should follow placement limitations. Check dams should not be placed where they will cause flooding damage, where they will cause damage to aquatic life, or in channels serving a large drainage area.

DESIGN CONSIDERATIONS

The initial cost of a check dam varies depending on the design dimensions. The following values represent cost estimates of a two-foot check dam for comparison purposes only (Virginia SWCC, 1980):

Structures	Cost
Temporary structures	
- Rock check dam	$18-30/cu. yd.
- Log check dam (general)	$490-740 each
Permanent Structures*	
- Sheet piling check dam $15/sq. ft.	$15,000-20,000 each
- Concrete check dam 30 ft. wide	$60,000-75,000 each

*Personal communication with Barr Engineering; 1982 values.

Installation costs vary with the materials used. Additional materials can be used to construct a better dam, such as riprap or filter material, but increases in costs will occur. Log check dams have cheaper material costs since logs and brush can be salvaged from site cleaning operations. However, log check dams require more time and hand labor to install. Many versions can be installed and cost will vary with the complexity and durability of the design. Stone check dam materials must be transported to the site, but material costs are compensated by low installation costs.

Concrete check dams are substantially more expensive than other types, which discourages their use as anything but a permanent installation. The material costs of sheet piling and concrete structures are similar. It is the installation cost that raises the price of concrete structures. Concrete requires additional grading, excavation, water diversion and dewatering that are all unnecessary when installing sheet piling.

O & M needs include regular inspections to make sure the check dam has not been damaged by construction activities or high flow velocities. Additional inspections should be planned after significant storms. On construction sites, where check dams are most commonly used, the contractor would be responsible for meeting the O & M needs. To keep the check dam operating properly the integrity of the dam should be maintained and damage to the dam repaired before a washout occurs. Other maintenance requirements include sediment removal once accumulations reach half the dam height.

Check dams are generally easily developed and can be constructed with either mechanical or manual labor. If they are applied within the design criteria few operational problems should develop. Most problem occurrences are due to lack of maintenance or under-designing the structure.

DETENTION

WATERWAY DETENTION

Waterway detention involves the planning and design of a channel capacity to temporarily detain high flows of discharge and release them at a lower flow rate and velocity. Detention directly in the waterway is achieved by the operation of a flow control structure such as a dam, weir, sluice gate, or pump. Detention can be applied to either open channel flows or in-line sewer flows.

OPEN CHANNEL DETENTION

Description and Purpose

Open channel detention can be created by designing waterways with enough excess capacity to provide temporary storage for periods of high runoff volumes. The purpose of open channel detention is to keep runoff in a stabilized area until it can be discharged at a controlled rate that will not cause excessive erosion or flooding. If designed properly, detention in open channels provides multiple benefits of erosion control, flood control, increased recreational value, sediment removal, water infiltration and quality control.

Detention can be created by the placement of a flow control structure such as a dam, check dam, weir or sluice gate. Structures such as check dams are inflexible, designed to detain only specific quantities of water. They are not flood control structures since it is difficult to vary the detention quantity. Dam structures detain variable amounts and can be calibrated to control flooding downstream. Dams are used not only to control high flows but to insure a minimum flow during dry periods. Used in a river or stream, dams can create permanent ponds that can increase an area's recreational value. Dams are a highly structural method that must be designed by a qualified engineer following the restrictions and regulations set by government agencies. Difficulties in detaining water with this method include damage to the upstream area used for water storage.

Another type of detention is to divert runoff through a series of channels where the increased distances will delay peak discharge. Typical channels used to delay runoff include ditches, swales, trenches and diversions. This method must be relatively extensive to create much of an impact. Channels that are pervious may reduce flow quantity by infiltration. Controls which slow velocities will improve water quality by promoting sediment settlement and decreasing bank erosion.

For more information on a specific flow control, see the appropriate section.

IN-LINE STORAGE

Description and Purpose

In-line storage detains urban runoff in the unused volume of combined or separated storm sewers for later release. Storage can be created by use of a flow restricting device (within a conduit or at the overflow point), on oversized pipe diameter, or pumping stations to control flows. Various designs and operation levels are available to provide a flexible system.

Presently, several of these systems are being applied in different cities with combined sewer systems. The purpose of this MP is to reduce the volume and occurrence rate of overflows. Combined sewer overflows occur when the combination of storm runoff and sanitary sewage exceeds the capacity of the sewer or treatment plant. When an overflow occurs, wastewater flows directly to a receiving body causing pollution impacts. By making use of existing storage capacities in the sewer lines, high flows can be held back to be discharged when flow levels fall below the overflow point. The higher the reduction of overflow events and the volume discharged during that time, the less pollution will impact the receiving waters. Similarly, excess stormwater can be stored inline for subsequent discharge and treatment.

Target Applications

This MP is aimed at preventing discharge of untreated sanitary sewage and/or stormwater runoff directly into a water body, thus protecting physical and biological quality, aesthetics and public health. These discharges are responsible for bacteria, floating material, sediment and organic problems in receiving waters, as well as resulting dissolved oxygen deficiencies. The target pollutants are all pollutants associated with both sanitary sewage and urban runoff, such as organics, pathogens, heavy metals, PCBs, sediments and nutrients.

In-line storage is applied when temporary storage is needed in combined or separate sewers. It is applied to sewer systems that have excess capacity available for use as storage. Besides providing stormwater control and preventing overflow events, it can be applied during dry weather. Runoff can be temporarily detained to assist the inspection and maintenance of either the sewerline or treatment plant.

Effectiveness

The effectiveness of in-line storage is dependent on the storge capacity and type of control. In-line storage can only detain a finite volume of water. Overflow will still occur whenever inflow to the system surpasses the allowable outflow and detention quantities. Off-line storage may be applied in addition to in-line storage to handle larger quantities of flow.

Effectiveness of the in-line control system at providing the full capacity of storage is variable. For combined sewer systems, the level of control, operator experience, types of equipment and the control system can all be manipulated to improve a system´s effectiveness. Automatic controls are more efficient than supervisory or local controls. As operators become more experienced, they are better able to judge storm impacts and system abilities.

In Minneapolis-St. Paul, inflatible fabridams were reported as reducing combined sewer overflow occurrences by 58 percent and total overflow duration by 88 percent, with spring thaw runoff contaminants reduced almost 100 percent (Lager and Smith, 1974). The Twin Cities system is only partially still in use. In Saginaw, Mich., in-line systems were assumed to reduce overflow volume by 50 percent (Lynard et al., 1980).

In-line storage detains polluted water until it can be discharged to a treatment facility. Data from Seattle, Wash., on the effect of in-line storage on pollutants discharged to receiving waters follows. The Seattle system consists of regulator stations controlled by computer augumented treatment and disposal (CATAD) system, and achieves pollution control as follows (Leiser, 1974):

Pollutant	Percent Reduction
Settleable Solids	66
NH_3-N	58
NO_3-N	80
PO_4	60
TSS	65
VSS	68
BOD	64
COD	76

Use of in-line storage for detention of separate stormwater is less documented than use for combined sewage. A recently completed Nationwide Urban Runoff Program (NURP) study in Michigan (U.S. EPA, 1982) showed that a dual in-line oversized pipe system yielded essentially zero reduction in pollution. The reason for this was scour of settled debris by subsequent events.

Planning Considerations

In-line storage is best applied to existing combined sewer systems. They generally have low capital costs since existing facilities are used. More expensive automated computerized systems have limited applications to larger systems since the base cost of the computer facilities would cause this method to be uneconomical. In-line storage provides a finite volume of storage; therefore, additional storage may be needed. One alternative, building additional in-line storage, is rarely cost effective; instead, additional storage is usually more economical in the form of off-line detention or sewer separation.

When selecting a method to reduce combined sewer overflows, factors that should be considered include topography, climate, land use, runoff and the combined sewer system. Both monitoring and control systems are needed to effectively use in-line storage. Monitoring equipment measures rainfall, flow level and quality elements to direct the use of regulating control systems.

In-line storage is usually applied to wet weather conditions, but has several dry weather applications. Water can be detained while sewer conduits and treatment plants are inspected and repaired. Some systems such as Seattle´s CATAD facility can monitor equipment operation and keep a constant data base of rainfall, flow level and quality.

Seattle´s system is perhaps the most complex presently in use. The system consists of 19 regulator stations and four pumping stations that provide 22.79 million gallons of storage (Lynard et al., 1980). Regulator stations are equipped with mechnical systems or hydraulically operated gates. Each station contains numerous monitoring points and a raingage network to supply operating quality and quantity data. The system is run by a centeralized computer facility plus two satellite control terminals at the treatment plants.

In Saginaw, Michigan, a combination of regulator improvements to increase in-line storage volumes and construction of storage/treatment facilities were applied. In-line storage reduces the size and cost of the storage basin. In this case, a parking garage was built over the underground basin. In-line storage provides 23.3 percent of the total storage capacity at only 5.1 percent of the total projects cost (Lynard et al., 1980).

The system in Seattle used both in-line storage as discussed previously and partial sewer separation. In this case, in-line storage provided 67 percent of the overflow reduction at 9.6 percent of the total capital cost, while sewer separation accounted for 38 percent of the total overflow reduction at 90.4 percent of the total capital cost (Lynard et al., 1980).

Design Considerations

The initial cost of using combined sewer systems for in-line storage is kept economical by using existing facilities. Actual costs will range from $95 per contributing acre for an in-line flow restriction to $1,400 per contributing acre for a complex computer controlled system (Lynard et al., 1980). Of course, a less costly alternative of controlling runoff at the source may also be implemented. Costs can be summarized as follows (Lager et al., 1977):

Location	Capital Cost ($ million)	Storage Cost ($/gallon)	Cost Per Acre ($/Acre)
Seattle, Wash.			
Control and monitoring system	$ 7.0	--	--
Automated regulator stations	7.8	--	--
Total	14.8	$.84	$1,128
Minneapolis, Minn.	6.0	--	94
Detroit, Mich.	5.6	.04	62
Saginaw, Mich.	4.9	.47	307

O & M needs should consist of preventive maintenance. Systems generally have low maintenance costs since normal inspection and maintenance of the sewer system is just expanded to include the control devices. However, O & M needs and costs will increase as the system becomes more complex. For instance, Seattle's system is highly reliable. It has monitors to check component operation and several back-up systems including manual override. For maintenance, two crews are required, one for the computer system and one to maintain the mechnical system. The following table breaks down the O & M expenditures. It should be kept in mind that most systems require much less; for instance, electrical rates are high from the running of the computer, labor requires technically capable employees and other costs include building rental. O & M costs for CATAD can be summarized as follows (Lynard et al., 1980):

	Labor and Fringes	Utilities	Other	Total
Remote Stations				
Operation	$191,900	$135,500	$ 3,100	$330,500
Maintenance	78,300	--	32,400	110,700
Subtotal	$270,200	$135,500	$35,500	$441,200
Central Computer Facilities				
Operation	$ 80,800	$ 8,400	$16,000*	$105,200
Maintenance	41,900	--	--	41,900
Subtotal	$122,700	$ 8,400	$16,000	$147,100
Total	$392,900	$143,900	$51,500	$588,300

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*Approximately 75 percent of this cost if building rental.

The system adaptibility regulates the ease of development and use. This method works well when connected with off-line storage and a computer controlled system such as Seattle´s can become the foundation for future expansion. Operations problems will vary with the type of system. Difficulties could be caused by inadequate design or installation. Equipment may lack the accuracy required to perform the job or improper installation could become a problem. Metal corrosion during use may cause difficulties, and odor problems may result from stagnant water in the system. Other system specific problems may occur. For instance, Seattle´s automatic computerized controls had problems with program bugs, documentation and hardware malfunction and design deficiencies. An additional difficulty occurred with electrical noise created problems with telemetry and data transmission. During regulator station construction, temporary public inconveniences occur, such as noise, increased air pollution and traffic disruption; however, these are minimal compared to those associated with sewer separation or large construction projects.

STRUCTURAL OFF-LINE STORAGE

DESCRIPTION AND PURPOSE

Structural off-line storage consists of detention facilities constructed to reduce peak runoff flows by providing temporary storage. The purpose of off-line storage is to improve water quality by preventing overflow discharge, or reducing the impacts of stormwater and its associated contaminants on the receiving waters. This might be achieved by capturing the "first flush," controlling storm flow peaks, reducing flow volumes and frequencies, and providing alternative treatment and auxiliary storage during treatment plant down times.

The methods of detention include detention tanks, underground structures, underwater storage and basins. Off-line storage methods are often varied for each application. Generally, off-line detention is designed for combined sewer areas where available land area is scarce to store runoff from large storm events until it can be discharged back to the sewer system without causing an overflow. Limited use of off-line storage can also be made for separate sewer systems.

Primary treatment facilities can be added to provide treatment of water being discharged into the receiving water for cases where the capacity of the detention facility will be exceeded. Typical treatment additions include sedimentation and chlorination. Emergency treatment facilities are not needed when storage facilities are capable of containing all overflow for future discharge back into the sewer system.

TARGET APPLICATIONS

The target pollutants are primarily contaminants associated with combined sewer overflow, sanitary sewage and polluted urban runoff.

Off-line storage can be applied when combined sewer overflow may create a health hazard or pollute receiving waters above recommended levels. Each specific application has different limiting factors. Surface detention facilities are applied when land areas are available for the required site. They are not applied when heavy densities or surrounding land uses are not compatible with the storage facility.

Underground tanks are only applied when other alternatives are infeasible because of site restrictions. These excavated tanks are costly and are usually applied when alternative ground surface uses are desired. Other underground facilities such as existing quarries or tunnels might be applied if it is proven viable during a cost-effective analysis. Underwater facilities can be used when discharging into a large water body and when alternative land storage is not available. Storage can occur in plastic bags or in any other type of prefabricated container.

EFFECTIVENESS

Off-line storage may effectively protect water quality in several different ways, including reduction of peak flows, reduction in overflows and direct treatment. By reducing peak flows, the downstream treatment process is not subjected to fluctuating loads. Reduction in discharges corresponds directly with a reduction of pollutants in the receiving water. Direct treatment either through facility design or by adding treatment facilities to the offline storage will directly reduce pollutants.

Off-line facilities constructed to detain excess flow volumes might not provide any direct water quality improvements. However, if all of an overflow is contained, 100 percent of the overflow pollutants would be reduced. It is usually uneconomical to design facilities large enough to detain all overflow; therefore, the effectiveness at improving water quality is substantially less.

Off-line facilities may be designed to improve the water quality for cases where discharge still occurs. The detention area can be designed as a settling basin to remove sediments and additional treatment facilities can be added to further remove pollutants.

Saginaw, Mich., has implemented a storage/treatment basin where overflows are contained and sent back for treatment in dry weather. Occasional overflows that exceed the detention capacity are treated by settling solids and disinfecting with chloride before discharging to the river. The effectiveness of the storage/treatment facility has been measured as 73 percent reduction in overflow frequency and 60 percent reduction in overflow volume (Lynard et al., 1980). The following pollutant reductions have also occurred in Saginaw:

	Reduction From Storage/Treatment	Reduction From Storage/Treatment and Dry Weather Treatment
Suspended solids	73%	89%
BOD	54	81
Heavy metals	44-69	--

The removal effectiveness will also vary with the storage facility design, storage volume, climate, detention time and additional treatment facilities. For instance, there will be a much higher removal rate during a dry year than a wet one. Efficiency has been shown to decrease as the tank size increases, as follows (Fitzpatrick et al., 1977):

Volume (Gallon/acre)	BOD Percent Removal	Suspended Solids Percent Removal
2,500	18	37
7,500	32	58
15,000	38	65
25,000	39	67

PLANNING CONSIDERATIONS

The storage facility capacity and type should be designed to meet influent volume and receiving water conditions. The design should be cost effective as well as compatible with water quality goals. To provide the optimum solution, a balance between storage and treatment will need to be planned. It may be more economical to design storage to contain low storm volumes since higher costs and lower efficiencies result from increasing the storage tank size.

Off-line storage can be designed for detention or as a facility that provides physical treatment. A basin can be designed to promote sedimentation and incorporate disinfection. Commonly applied treatment methods include coarse and fine screening, solids concentration and disinfection.

The location of the storage facility will be determined by the type and function of the off-line storage. Off-line storage can be applied at the overflow point, near the treatment facility or as on-site storage at the runoff area. A simple earthen storage basin aimed at reducing flooding or sewer overflow by controlling peak flows is likely to be located at the source on-site. A concrete detention tank with storage and emergency primary treatment is best used at an overflow point.

The type of detention facility should be chosen as the one that will best provide the needed protection and fit the site requirements. Basins are perhaps the most commonly used method. They can be made from earth, concrete or asphalt. The use of basins is limited in high density areas by land costs and availability. Detention basins may have problems controlling odor, algae, insects and aesthetic appearances. These problems make it difficult to obtain public acceptance in neighboring areas, though proper location, design and maintenance may minimize the problems.

Underground foundations might be constructed from tunnels, mined quarries, excavations or concrete detention tanks. Underground detention is best used when land limitations make surface storage unavailable, since it tends to be an expensive method. Because of the expense, underground storage will most frequently be used on highly polluted runoffs such as combined sewer overflows containing sanitary sewage. Benefits of using underground storage include low land use, surface availability for alternative uses and absence of typical surface problems such as algae, insect and visually unappealing structures.

Underwater storage facilities that have been tested are an epoxy coated steel and neoprene coated fabric and a steel tank with flexible diaphram (Athayde and Waldo, 1977). This method does not require land area but can only be used near a large body of water. It is best used to contain combined sewer overflow until it can be released back to the sewer system for treatment.

DESIGN CONSIDERATONS

The ease of development and use will vary with the facility type. Surface detention facilities seem to suffer from fewer of the operational problems that are experienced by underground and underwater pilot test plants, though surface facilities require maintenance to control odor, algae and visual appearances. Covering surface tanks or other solutions may be designed to control these problems.

Underwater storage facilities are still considered experimental. Pilot facilities were operated for short time spans and had several operational problems. In Cambridge, Maryland, because of public disapproval, the pilot plant was removed before it was properly evaluated (Lager et al., 1977). This demonstrates the need to include public acceptance as one of the planning considerations. In Washington, D.C., operational problems of bag anchoring and tearing and general equipment malfunctions occurred and in Sandusky, Ohio, equipment operation malfunctions and silt accumulations made usage difficult (Lager et al., 1977).

The initial costs will vary with each site depending on the detention facility design and site factors. The following table gives the cost of a detention tank for increasing volumes (Fitzpatrick et al., 1977):

Volume (Gallon/acre)	Capital Cost* ($/acre)
2,500	$ 2,800
7,500	8,600
15,000	17,200
25,000	28,800

*Land costs not included.

The following table shows initial costs and O & M costs for specific applications (Lager et al., 1977). These off-line facilities are all designed to deal with combined sewer overflows. Most of the facilities are equipped with additional treatment operation. O & M needs will be the responsibility of the owner, which in most cases, is the local sewer utility.

Location	Description	Storage Cost ($/gal.)	Initial Cost ($/acre)	O & M Cost ($/year/acre)
Sandusky, Ohio	Offshore underwater storage facility, nylon reinforced synthetic rubber storage tanks.	$ 2.88	$70,000	$1,440.00
Washington, D.C.	Offshore underwater storage facility, nylon reinforced synthetic rubber storage tanks.	8.82	58,860	222.67
Cambridge, Md.	Offshore storage facility, steel storage tank with a flexible rubber diaphragm.	2.56	32,000	1,440.00

Location	Description	Storage Cost ($/gal.)	Initial Cost ($/acre)	O & M Cost ($/year/acre)
Saginaw, Mich.	Storage tanks with two-level garage above.*	2.61	5,733	31.25
	Multicell storage reseroir, concrete underground tank, initial chamber settling tank.	--	12,000	320.00
Milwaukee, Wis.	Covered concrete storage tank.*	.90	6,200	1,440.00
Boston, Mass.	Covered concrete storage tank.*	10.00	832	10.26
New York, N.Y.	Covered concrete storage tank.*	1.92	7,320	61.47
Chippewa Falls, Wis.	Open asphalt lined storage basin.*	0.52	16,540	60.00
Columbus, Oh	Open concrete stormwater tanks.*	3.28	420	--
Akron, Oh	Underground storage tanks, plastic lined storage basin filled with inert aggregate.*	0.82	4,840	30.77
Chicago, Ill.	Deep tunnel storage, tunnels for transmission and storage, mined quarry for additional storage.			
	- Tunnels and pumping	0.58	7,260	--
	- Reservoirs	0.04	5,680	--
	- Total*	0.08	21,280	72.50

*Additional treatment measures applied but not listed. Land costs not included.

EXISTING NATURAL DETENTION

DESCRIPTION AND PURPOSE

Existing natural detention should be used when creating surface water storage areas. Lowlands, wetlands and floodplains are areas naturally suited for providing water storage. If properly designed, these areas require less construction at lower costs than detention facilities in other areas. For instance, one study determined wetlands storage to be 10 percent of the cost of a comparable storage pond requiring substantial excavation (Lynard et al., 1980).

These areas are also well suited for a multipurpose design. They can be used as recreational areas, parks, wildlife refuges or golf courses. Design and planning is extremely important for multiuse facilities to arrange compatible activities with the detention requirements.

The purpose of using existing natural detention is to provide storage which will reduce peak flows and flooding, provide opportunities to increase infiltration and sedimentation, and provide biological treatment for water quality improvement. Natural detention takes advantage of the existing drainage system and can be designed to utilize property that is undesirable for development, such as floodplains. For details, see the appropriate sections on wetlands and land use planning.

ON-SITE DETENTION

DESCRIPTION AND PURPOSE

On-site detention is one method of storing stormwater at the site. As areas become urbanized and develop higher percentages of impervious ground surfaces, runoff volumes increase causing quantity and associated quality problems downstream. The purpose of applying on-site detention is to detain high runoff volumes during peak flows for discharge at a later time and at a controlled rate when the effect on the conveyance waterway will be minimized.

Examples of on-site detention include basins, parking lots, plazas and rooftops. Other storage methods can be applied to provide temporary on-site storage. Gravel filled trenches, swales and pervious basins are all on-site infiltration storage methods that are discussed in the infiltration section.

On-site basins are perhaps the most commonly applied technique of on-site storage. A variety of basin types can be used for temporary or permanent, dry or wet storage, infiltration, sedimentation and treatment. Further discussion of these methods can be found in the following section on Ponding.

Parking lot detention is the temporary storage of stormwater on the paved parking surface. Lots can be graded to direct runoff towards designated areas designed to least inconvenience users. The stored water is then drained at a controlled rate using a flow restriction device such as an orifice plate. Additional MPs may be applied to promote infiltration such as porous pavement or infiltration trenches.

Paved plazas constructed in or around commercial and office buildings can be designed to provide temporary water storage. Plazas can be designed with depressed sections which store water without inconviencing pedestrian traffic.

Rooftops can be designed to detain rainwater for release at a controlled rate. This method is usually applied to flat roofs that have drainage controls constructed to provide a maximum discharge rate. Additional overflow drains must also be installed to prevent detention levels above the design capacity, and structural reinforcement might be needed.

TARGET APPLICATIONS

On-site detention is usually aimed at correcting a water quantity problem, but adaptations can be made for quality enhancement. The method does not necessarily reduce total runoff volume or remove all existing runoff pollutants. It may reduce flooding, stream channel erosion and combined sewer overflows caused by high flow levels. By reducing the occurrence and duration of these events, an unquantified amount of associated pollutants will be controlled.

This method is applied when impervious surfaces, which accompany urbanization, produce high quantities of runoff or when construction activities disturb the land surface. Large impervious areas disturb natural drainage and infiltration patterns, creating large volumes of concentrated runoff which may result in flow levels above the safe capacity of downstream waterways. Construction activities disturb the soil and expose new areas to erosion. Rooftops can make up a significant portion of the total surface area, especially in developed commercial areas. The flat roofs found on commercial and industrial buildings adapt well as rainfall storage areas. Expansions of paving, such as shopping center parking lots or truck terminal lots, are also prime candidates for on-site detention facilities. It is often best to apply detention facilities during construction since detention can be included in the original facility design and minimal additional construction will be required.

EFFECTIVENESS

The effectiveness of on-site detention at reducing peak runoff flows will be dependent on the available storage volume and the release rate of the outlet control. In one case, reduction of total peak stormwater runoff has been reported between five and 11 percent when two to four percent of the land area is covered with flat roofed buildings which were used for storage (Stanley Consultants, 1976).

Neither total runoff volume reduction nor efficient pollutant removal is obtained by using on-site detention. Positive effects on water quality may occur if infiltration detention is applied; for example, lower peak flows prevent streambank erosions and associated sediment loadings, and increased detention time causes some sediments to settle out. The actual water quality benefits have not been quantified.

PLANNING CONSIDERATIONS

On-site detention is best used when properly designed to allow the maximum level of control with the minimal amount of difficulties. Permanent on-site detention facilities should be integrated into the landscape, for example a basin could be developed as open space, recreational area or park, or an existing impervious surface can be used for detention along with its primary purpose as a parking lot, plaza, or rooftop.

On-site detention as an MP is usually applied in combination with a large impervious surface or with construction. Rooftop and parking lot detention utilizes the source of increased runoff for storage.

On-site detention facilities can usually be created with only slight site modifications. Outlets are installed to discharge the stored water at determined rates either by pipe capacity limitations or orifice plates. Overflow structures are installed to keep the detained water below a maximum height.

Parking lot storage can be designed to provide temporary runoff water storage as a method of reducing peak sewer loadings. The total storage volume will be determined by the detention area size and maximum allowable storage depth. The lot should be graded to direct water to the designed storage area. Steeper than normal slopes may be required to adequately drain runoff to the detention area, though the steepness is limited by the need for vehicles and pedestrians to travel up slopes in icy conditions. The detention area on the lot can be designed as a depressed area.

Parking lot storage should be designed to prevent disturbances of lot users. For instance, using the overflow parking section of a shopping center parking lot is less likely to interfere with users. Though there are no structural limitations on water depth, this method is considered a low depth storage pond. To prevent interference with parking and for safety, water should not be detained for long periods of time or beyond a shallow depth. The depth and detention time can be controlled by designing for a high discharge rate and by installing overflow devices.

Rooftop storage can be designed as part of new buildings or modifications or existing structures. Rooftop storage is limited to horizontal, nearly flat surfaces. Most buildings are designed to withstand additional rooftop loadings, in which case very few structural modifications would be needed. Rooftop storage is created by adding additional waterproofing, and installing a parapet wall and outlet control. Perforated risers with limited capacities are often placed on the downpipe inlet as one method to control discharge.

Rooftop storage uses a frequently unused resource. It does not require an aesthetically pleasing design since it is rarely visible. Rooftop storage does not interfere with traffic or building use. Special design concerns include a limited storage volume. Overflow controls must be installed for cases where rainfall exceeds the storage volume and the discharge rate. Rooftop storage volume is limited by two physical concerns, that is, storage area and roof loading conditions. Additional planning can be used to dispose of rooftop runoff using alternatives to the conventional direct discharge into the sewer line. Alternatives include, surface drainage, subsurface infiltration and runoff collection and storage.

Use of on-site detention depends upon the design specifics, with basins widely used and rooftop storage seldom used. Stormwater control is regulated by local levels of control. Available methods to do so include zoning ordinances, subdivision regulations, building codes, plumbing and sewer ordinances, flood and water pollution control ordinances. For instance, the Denver Urban Renewal Agency requires rooftop storage be incorporated into the design of buildings. Other agencies have legislation requiring that runoff quantities remain at predevelopment levels, with the choice of control methods left up to the developer.

DESIGN CONSIDERATIONS

All of these types of on-site storage must be specially designed to overcome difficulties associated with their use as a detention method. In each case, the detention must be designed to avoid interference with the facilities primary use by not inconveniencing users or damaging property. Other development and use difficulties that should be considered during the detention facility design include safety hazard to children, maintenance difficulties, mosquito or algae problems, visual appearance and land use requirements. Proper design may eliminate or decrease these problems.

The use of existing surfaces for detention will be cost effective if only a minimal amount of additional construction will be required. For instance, a parking lot with detention facilities will require only a slight increase in grading, but the decrease in runoff may allow smaller downstream systems. Rooftop storage will be cost effective if substantial additions in the design are not needed to increase the loading capacity. Rooftop storage has been estimated at range of $.03 to $.17 per square foot of roof area (Stanley Consultants, 1976).

O & M needs vary depending on the type of facility. O & M will be the responsibility of the property owner. Maintenance requirements include landscape care and debris removal, removal of deposits in sediment ponds and drain maintenance for rooftop and parking lot storage. The need for permanent detention facilities often occurs in public areas such as dense commercial and residential areas. Therefore, high levels of maintenance and landscaping are required. Parking lots may be kept clean by sweeping, but rooftops need little maintenance for visual upkeep. Both parking lots and rooftops require drain upkeep to prevent clogging from debris, leaves or sediments. This is particularly important for rooftop drains where backups may cause damage to the building and its contents.

PONDING

Variables dictating the use of detention include the availability of land, the type of drainage (sewers or open channel), land use and target pollutants. Ponds may be constructed on-site or off-site. The design can be varied to provide easier use; for example, detention facilities may be dry or wet. Ponding is created by excavating a basin, by storing in natural depressions, by constructing an embankment, or by constructing a dam across a waterway.

Ponding can be designed for detention, infiltration, sedimentation or treatment. The main purpose of each of these ponding types varies. Detention ponding detains stormwater, controlling the discharge rate to prevent flooding, overflows or erosively high flow levels. Infiltration ponding promotes percolation of water into the soil, thus reducing runoff quantities and replenishing groundwater supplies. Sedimentation ponding removes suspended solids from the detained water by promoting settlement. Treatment ponding removes pollutants by combining treatment systems with detention.

Ponding can be designed to provide additional "conjunctive" or multiuse benefits. Besides controlling surface water and reducing pollutants, ponding can be designed to provide a municipal, industrial or agricultural water supply. Detained water can be planned to improve the wildlife environment and for recreational or aesthetic use. Conjunctive use spreads the benefits, and possibly the costs, of a facility among several uses.

The use of any ponding method may be limited by land requirements. Property in heavily developed areas is rarely available or is extremely expensive. Therefore, ponding is more likely to be applied to developing areas. When considering any type of ponding the impacts should be evaluated. The effect of altering flows through stormwater control may not be beneficial to downstream areas. Negative impacts on surrounding areas could result from the use of ponding. Infiltration ponding of polluted waters might be a potential hazard to groundwater quality. The use of ponds as recreational areas will be difficult unless methods to control algae growth and insect breeding, and to maintain landscaping and safety are planned.

DETENTION PONDING

Description and Purpose

Detention is the most fundamental type of ponding. Detention ponding is formed by constructing a barrier or dam across a waterway, excavating a basin or building a detention tank. The purpose of detention ponding is not to directly remove pollutant or reduce runoff quantities, but temporarily delay runoff or high channel flows. Detention ponding controls the discharge rate by storing a specific volume of stormwater runoff for a designed period of time.

Detention ponding can be designed to supply additional pollution control by reducing runoff quantities and incorporating runoff quality improvement techniques. These methods include infiltration, sedimentation and treatment ponding. Discussions of these methods can be found in the sections directly following this section.

Target Applications

Detention ponding is a quantity control method aimed at reducing peak flow volumes, and a quality control method that takes advantage of the natural settling that occurs in ponded water. By reducing peak flow volumes and velocities, sediment loading from bank erosion and scouring is also reduced. Detention ponding can be applied downstream of an impervious area to control high runoff quantities, or on-site to collect for a small area, or as a regional system. Detention ponding can be applied in-line or off-line.

Effectiveness

The effectiveness of storage basins can be measured by either peak flow reduction or pollutant containment. In Montgomery County, Maryland detention basins are used as off-site detention facilities (Lynard et al., 1980). In one basin designed to detain small volume, short duration storms, peak flow was reduced 90 percent for the design storm runoff quantity and 66 percent for larger volume, longer duration storm events. Sediment trapping efficiencies were reported between 88 to 92 percent, with basin operation performance better on smaller storms. The following table demonstrates the general trapping efficiencies of the Maryland detention basin on different types of pollutants under different storm events (Lynard et al., 1980):

Predicted Trap Efficiencies From Storms of Varying Duration and Frequency (Percent/Reduction)

	2-yr. storm duration, hr.			10-yr. storm duration, hr.		
Parameter	0.5	1.0	2.0	0.5	1.0	2.0
BOD_5	91	88	86	86	81	79
COD	76	67	57	57	45	37
TOC	84	80	75	76	68	64
TP	22	17	15	17	13	10
NH_3- N	92	90	88	85	77	76
Zinc	98	97	96	96	95	94
Cadmium	79	77	70	76	73	68
Lead	97	97	96	97	96	96
Iron	92	90	87	89	85	83

The effectiveness of a detention pond will depend on the basin design and loading factors. Basins may be designed to detain different amounts of storm runoff. Usually basins are planned for a chosen design storm. The efficiency of the basin will drop when an actual storm event is greater than the design storm. Efficiency will also be lower in areas where large percentages of impervious surfaces increase runoff volumes, and in cases where maintenance is not performed and storage volume is reduced by sediment. The following table (Moreau and LaPointe, 1979) illustrates the relationship between basin size, watershed type, design storm and removal efficiency for a 200-acre watershed. The table shows how diminishing rate of return might encourage the use of basins designed to collect smaller quantities of runoff.

Watershed Type and Treatment	Design Storm	% of Runoff Detained	Basin Volume 10 ft	Basin Area 10 ft	Solids Removal Efficiency 2-month Storm	Solids Removal Efficiency 2-year Storm
High density residential with conventional drainage	2-month	30	96	9.6	52.4	45.6
		60	192	19.2	81.1	70.1
		100	319	31.9	100.0	87.1
	2-year	30	283	28.3	83.6	96.2
		60	566	56.6	97.5	100.0
		100	944	94.4	100.0	100.0
High density residential with reduced runoff drainage	2-month	30	55	5.5	42.9	30.0
		60	110	11.0	73.2	51.3
		100	183	18.3	100.0	70.1
	2-year	30	186	18.6	100.0	70.7
		60	372	37.2	100.0	92.4
		100	620	62.0	100.0	100.0
Commercial with conventional drainage	2-month	30	51	5.1	52.4	28.4
		60	102	10.2	81.1	48.9
		100	171	17.1	100.0	67.8
	2-year	30	175	17.5	96.2	68.7
		60	350	35.0	100.0	91.3
		100	583	58.3	100.0	100.0
Commercial with reduced runoff drainage	2-month	30	39	3.9	39.0	23.1
		60	78	7.8	69.7	41.0
		100	130	13.0	100.0	58.9
	2-year	30	145	14.5	100.0	63.1
		60	290	29.0	100.0	88.2
		100	484	48.4	100.0	100.0

Planning Considerations

To provide the best use of detention ponding, the facility design must be appropriate. The detention pond design includes inlet and outlet structures and basin configuration. Detention ponds are created by using a restricted outlet to control the discharge rate into the drainage system. The pond must be designed to deal with inflow quantities which depend on the design storm (frequency, duration, discharge) and the surrounding area (topography, land use).

Detention ponds may accumulate silt and urban debris, promote mosquito and algae growth or become safety hazards. These concerns should be addressed in the planning stage to prevent difficulties. When possible, detention ponds should be designed to provide multiple use. Besides detaining water, ponds may provide recreation and wildlife facilities, improve aesthetics or provide a water supply source. The impacts on the pond's effectiveness should be considered when the facility is designed for multiple use.

Detention ponds can be designed as wet or dry ponds. Wet ponds are permanent pools with the storage volume above a minimum water surface level. Wet ponds provide sufficient detention times to promote good sedimentation. Dry ponds provide detention but not good quality improvement, since settled pollutants will be resuspended and washed out with each new storm event. The NURP studies on wet versus dry ponds found wet ponds far superior in improving water quality (U. S. EPA, 1982).

Wet ponds can be used as recreational areas, but require extensive maintenance and planning to cope with use problems. To maintain an aesthetically pleasing appearance, ponds that are wet periodically need devegetating. Mosquito breeding can be controlled by designing for complete drying between storm events or by chemical control.

Design Considerations

Ponding costs are dependent upon land availability and surrounding land use. Developing ponds in urbanized areas requires larger expenditures, since land costs are higher, and basins require more planning to make them publicly acceptable, and increased quantities of runoff come from the increased impervious land. Higher initial costs will occur when larger amounts of construction are required in excavation or embankment construction, or when the design requires additional construction to provide infiltration, sedimentation or treatment. Basin materials will also control the cost. Earthen basins have been reported as costing up to four times less than comparable concrete facilities.

The following initial costs are reflective of detention costs for the Twin Cities area (Metropolitan Council, 1982):

Detention Type	Cost ($/acre-foot)
Rural	
Wetland/lowland	$ 25-250
Urban	
Detention basin	50-3,000
Wetland/lowland	250-500
Infiltration	1,000-5,000

O & M needs include removal of debris, sediment and unwanted vegetation and general appearance upkeep. Detention facilities in public areas will require higher levels of maintenance to keep the area aesthetically acceptable. Maintenance is generally the responsibility of the property owner. Unless previously arranged, private owners do not always maintain the facility; therefore, public agencies are encouraged to take responsibility to assure detention pond maintenance.

INFILTRATION PONDING

Description and Purpose

Infiltration ponds are detention basins constructed in a manner to promote percolation of the detained water. Infiltration can be enhanced by installing perforated outlets or constructing a basin with a highly pervious bottom.

The purpose is to control runoff by reducing the flow volume, recharge groundwater supplies and reduce pollutants delivered to the waterway. Infiltration ponds cannot be used on heavily loaded runoff water, such as combined sewer or runoff from a disturbed area since large volumes of settling solids will quickly destroy the basin's percolating ability, and unwanted contaminants might seep into the groundwater system.

More information can be found under Infiltration in the Pervious Detention Facility section.

SEDIMENTATION PONDING

Description and Purpose

Most detention ponding is constructed to promote sedimentation. The purpose of a sedimentation pond is to trap and retain sediment. Sediment ponding can be designed as a temporary debris basin or as a permanent settling basin.

Temporary sediment basins are created by constructing a barrier across a drainageway or by excavating a basin. Temporary sediment basins are constructed below temporarily disturbed areas such as construction sites. The purpose of these basins is to control the runoff rate, improve water quality by trapping debris and sediments and protect waterways and land areas from silt.

Permanent sediment basins can be constructed with earthen, concrete or asphalt materials. They are most frequently applied to retain sediments and debris, though permanent facilities might also be constructed to deal with heavily loaded runoff and to control the stormwater runoff rate.

Target Applications

Sediment ponding is aimed at removing suspended solids. Since it is difficult to control solubles or fine-grained particles, the target pollutants are coarse- and medium-grained sediments. Settling basins are also capable of detaining smaller percentages of organics and nutrients.

Sedimentation ponds are used when runoff contains heavy sediment loads that will negatively impact downstream waterways and property or receiving waters. Unless heavy sediment loads are removed from runoff, the solids may be deposited downstream, clogging the waterway or covering property with silt, and the water quality will be decreased.

Temporary sediment basins are used when construction exposes a land area leaving it temporarily unstable. The basin should be constructed below the disturbed area. As a temporary measure, the basin should only be used for a specified time period, after which the basin should be regraded and stabilized.

Permanent settling can be used to control runoff from large areas of disturbed slopes or sediment-laden impervious surfaces. Generally, settling basins are used only when physical circumstances make alternative drainage control and erosion stabilization methods inadequate. Permanent settling basins can be used when combined sewer overflows are causing receiving water quality problems. As discussed in the off-line storage section, storage/sedimentation basins are constructed to contain small overflow events, and treat larger events by settling and disinfection before discharging to the receiving water.

Sedimentation basins can be applied when sufficient space is available and the topography is compatible for basin operation. Sedimentation basins should not be applied unless maintenance requirements are going to be provided, or when their use will have detrimental effects on surrounding land areas or aquatic life.

Effectiveness

Sedimentation basins directly improve water quality by removing suspended solids and associated pollutants. The efficiency of a specific basin will be dependent on the design and loading criteria. For instance, varying the volume capacity, design storm detention time, location and outlet design will vary the effectiveness. Sediment removal efficiences for a construction site basin were generally found to be as follows in one study (Athayde and Waldo, 1977):

Basin Type	Percent Sediment Removal
50-70	Small sediment basin
80	Downstream sediment basin
90	Sediment basin with chemical flocculants

The location, design and purpose of the sediment basin will vary the effectiveness. Effectiveness of sediment removal has been reported anywhere between 50-95 percent, depending on the facility. Generally, the removal relationship between pollutants remains the same. The following example from Orange County, Florida, demonstrates the removal efficiencies for different types of pollutants (Lynard et al., 1980) for detention/sedimentation:

Pollutant	Average Removal Efficiency
BOD_5	60%
TN & TP	76%
TSS	84%

Figure 21 is a NURP graphic that shows the pollutant reductions as a function of basin size for basins in this geographic area (E. D. Driscoll, personal communication).

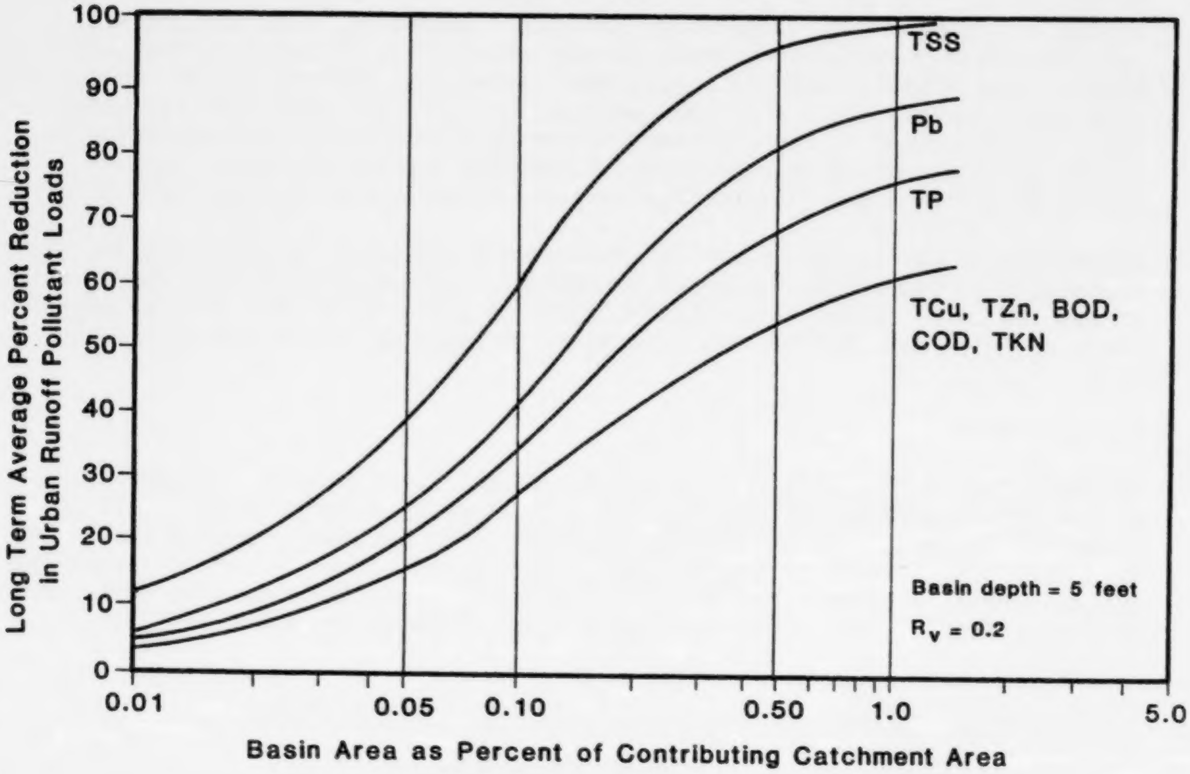

Figure 21. Preliminary Estimate of Detention/Sedimentation Basin Performance in the Great Lakes Basin.
Source: E.D. Driscoll, personal communication.

Planning Considerations

Settling basins are an integration of storage and treatment methodologies. Settling basins store runoff which controls runoff rates. Suspended solids are settled out naturally by detaining water long enough to allow gravity to separate the solids, or by installing additional treatment devices such as chemical clarification and screening. Treatment can be enhanced by providing a volume for permanent retention of settled material. Such a volume can be achieved by installing the outlet to withdraw outflow from somehwere in the water column rather than from the basin bottom (Figure 22). Additional physical treatment operations are frequently added to settling basins are deal with combined sewer flow.

When properly designed, constructed and maintained, settling basins are capable of removing high percentages of pollutants (see Figure 21). The design will depend on basin use, drainage area, loading rates and runoff volume. To provide the best design, the following must be included in the plans: site preparation, basin specifics, embankment slopes, and design specifics of the principal and emergency spillways.

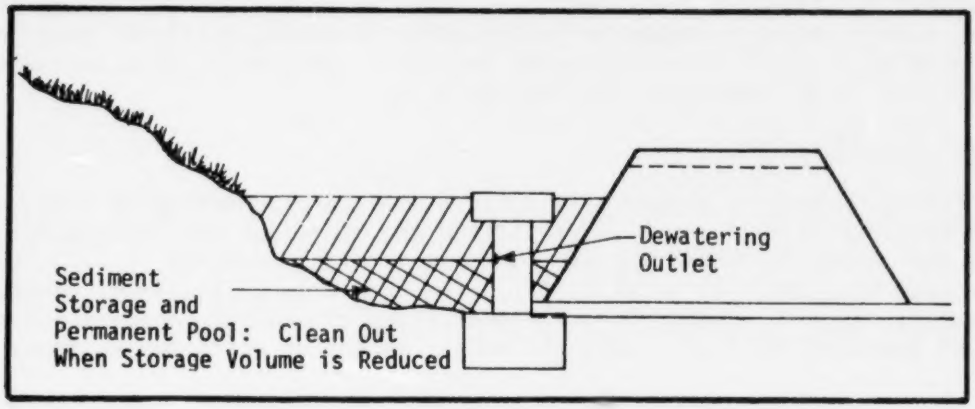
Dewatering Outlet
Sediment Storage and Permanent Pool: Clean Out When Storage Volume is Reduced

Figure 22. Sedimentation Pond Designed to Enhance Settling
Source: Virginia SWCC, 1980

The facility should be protected against erosion. Earthen embankments require rapid vegetative stabilization, and outlets should be provided with outlet protection such as riprap. The inlet and outlets should be designed to handle overflow without damage. Additional devices that are often included in the basin design to aid in the safe and effective operation include: baffles, trash racks, anti-seep collars, and safety devices such as warning signs and fencing.

When designing a settling basin capable of providing the required treatment, capacity considerations must be made. The required storage volume can be calculated by considering sediment loading factors and runoff volume requirements. The basin size should allow runoff detention for a period of time capable of providing the desired settling. The speed with which runoff is routed through the basin is controlled by the outlet structure.

The basin is expected to trap sediment; therefore, a method of maintaining the required basin capacity should be included in the design. Short-term, temporary basins may be designed with enough volume to collect sediments throughout its life span and still provide the necessary runoff detention. Settling basins operating for longer periods of time will require periodic sediment removal to maintain the required capacity.

Sediment basins require large amounts of maintenance to keep them operating effectively. They should be located where easy access is available. Location should also be chosen as the point where maximum effectiveness and minimal site disturbance are provided at the lowest cost.

On-site small-scale sediment storage is often the best choice for construction areas. This temporary measure will require additional planning for the final removal. Once the upstream drainage area is stabilized, excess water is drained, the basin site is stabilized by grading and vegetating, and excess materials are removed.

Settling basin design and construction should be in accordance with the criteria set by state and local agencies. Dams where failure will cause loss of life, severe property damage or interruption of public utilities must be designed by a qualified professional engineer. Generally, this includes permanent and large temporary settling basins.

Design Considerations

The initial cost of a sedimentation basin will vary according to site and design specifications. The site specifications, location and topography will vary the amount of excavation and embankment height required, while site access will determine the cost of transport. The design specifications, permanent or temporary, materials (concrete, earthen, asphalt), volume capacity and additional treatment will also vary the cost. Ranges of costs for sediment basins:

Temporary Sediment Basins*	$70-370/acre of drainage area
Detention/Sedimentation Basins**	$1300-5700/acre of drainage area

*Virginia SWCC, 1980.
**Lynard et al., 1980.

The following table (Moreau and LaPointe, 1979) provides equivalent annual costs for settling basins. Several conclusions can be made on the most cost-effective alternative. Settling basins designed for 2-month storms are more cost effective than those designed larger to handle two-year storms. There is a significant savings when drainage controls are used to reduce runoff. The table was calculated from national data using a 200-acre watershed, with alternative land uses, concrete settling basin with varying design parameters and on-site drainage controls.

Equivalent Annual Settling Basin Costs*

On-Site Drainage Practice	Storm Design Criteria	Basin Surface Area (acres)	Average Cost/1% TSS Removed In Two-Month Storm
Convention	2-year	0.26	1.00
		0.17	0.71
	2-month	0.09	0.45
		0.05	0.29
Reduced Runoff	2-year	0.15	0.63
		0.11	0.52
	2-month	0.05	0.31
		0.03	0.22

*1976 cost figures. Land costs not included.

O & M requirements to keep a settling basin operating are extensive. Basins collect sediments at fast rates, and to maintain usefulness, sediments must be removed. Also, the maintenance requirements of ordinary detention basins should be met, including debris removal, landscape care, insect control and aquatic vegetation control. Maintenance needs will be the responsibility of the owner. Temporary basins on construction sites should be the responsibility of the contractor, while permanent basins used for combined sewer control will be maintained by the local sewer utility. Annual sediment basin O & M costs have been estimated between $160-540/acre of pond (Athayde and Waldo, 1977).

The development of settling basins is limited by the need for available land. Also, they should not be applied unless proper maintenance will be provided. Lack of maintenance or improper design might cause difficulties to occur such as sediment resuspension during large storm events or outlets becoming clogged.

TREATMENT PONDING

Description and Purpose

Treatment ponding involves the application of physical, biological or chemical treatment during detention. Pollution reduction methods can be created from combinations of detention with a treatment system. Physical treatment systems that work well with ponding include floatable skimming, screening and filtration. Examples of biological treatment systems used with ponding are aeration and biological filteration. Chemical treatment methods include chemical clarification and disinfection (chlorination).

The application of detention may provide direct treatment without additional systems. For example, sedimentation is a physical treatment method where detention ponds treat runoff by settling the suspended solids. Sedimentation can be applied as a single basin or as a more complex series of tandem ponding.

The purpose of each treatment method is to remove pollutants. Biological treatment removes organics and nutrients, while physical treatment is aimed at solids. A trash rack would remove large debris, while a skimmer would be used to remove oil and floating debris. The more expensive treatment methods are most frequently applied to combined sewer flows. The purpose of these methods is to remove various pollutants, especially organics, before discharging to a water body. Ponding treatment improves water quality, protects against health hazards, and improves the aesthetics of the receiving water.

For further information, see the Treatment chapter.

TREATMENT

LOW INTENSITY TREATMENT

DESCRIPTION AND PURPOSE

Low intensity treatment uses methods that have very low degrees of active mechanically or technically oriented treatment. Low intensity facilities tend to provide physical treatment. Detention methods, sedimentation or wetland discharge are commonly applied as low intensity treatment. Low intensity improvements such as floatable skimmers and inlet/outlet screening can be applied for additional water quality benefits.

The purpose of low intensity treatment is to remove significant quantities of pollutants before discharging to further treatment or a receiving water. As a pretreatment method, low intensity operations improve the effectiveness of additional treatment. When used as the only treatment method, low intensity treatment protects the water quality of the receiving water by removing variable quantities of solids and associated pollutants.

TARGET APPLICATIONS

The target pollutants for low intensity treatment methods are floating debris,settleable and suspended solids, and pollutants associated with solids (metals, COD, nutrients).

Low intensity treatment is applied when nonstructural or source controls are inadequate, and it can be applied to concentrated runoff. Unlike high intensity treatment, these methods operate well under the variable conditions of nonpoint source runoff. They are used when runoff pollutant levels exceed acceptable standards. Low intensity treatment can also be applied as a pretreatment or treatment combination when dealing with combined sewage.

EFFECTIVENESS

The effectiveness of low intensity treatment methods will vary with the design, application site and loading factors. Generally, low intensity treatment is intented to remove specifically targeted pollutants. For instance, sedimentation methods reduce high percentages of suspended solids and the addition of floatable skimmers will remove surface debris and oil, while bar screens will remove larger solids. Pollutants associated with solids and floatables will also be removed to some extent while the target pollutant is reduced. Bar screens may remove 100 percent of the design pollutant (tires, logs, large debris), but those specialized items may only make up a small percentage of the total suspended solids. The following table lists general water quality improvements for various low intensity methods (Lager et al., 1977; Lynard et al., 1980; Oberts, 1980):

Pollutant	Pollutant Reduction Efficiency (Percent Reduction)			
	Detention/ Sedimentation	Wetlands	Static Screens, 250-1600 Micron Aperture	Bar Screen
TSS	20-95	75-95	5-25	3
BOD_5	30-60	--	0-20	1
COD	34	50	13	--
Settleable solids	30-90	--	10-60	--
Total phosphorus	20-76 variable	10	--	
Total Kjeldahl nitrogen	38-76 variable	8	--	

PLANNING CONSIDERATIONS

Low intensity methods are well suited for use on nonpoint source pollution. Low intensity treatment can be applied as singular treatment, pretreatment or in combination with high intensity treatment.

Detention methods provide the most common types of low intensity treatment. When dealing with combined sewer flow storage can be used to regulate flows and prevent overflows. It can also be designed as a treatment process by promoting settling. When applied as the main treatment process, sedimentation removes settleable and suspended solids. As a pretreatment method, heavier solids are settled out in an effort to increase removal of the remaining pollutants by the treatment facility. Sedimentation is also applied with high intensity methods as part of the treatment series. Prescreening, postscreening and floatable removal are three low intensity procedures often added to sedimentation facilities to remove pollutants not affected by settling.

Floatable skimmers remove oil, grease and surface debris in detention areas. Floatable skimmers are best applied to detention areas or wetlands where sedimentation will remove heavier particles but have no effect on floating objects. This method is valuable since it is one of the few that effectively deals with oil and grease and floating organic debris. Floatable skimmers are used on runoff water or water from combined sewers and are particularly effective in parking areas, wetlands, and detention outlets.

Inlet/outlet screening devices can be installed in detention areas for additional removal of pollutants. Low intensity devices which hold back pollutants include baffle weirs, bar racks and large aperture static screens. Nonpoint source runoff may have large floating debris; detention of these objects protects against impeded flow in open channels or pipes and prevents damage of downstream equipment (pumps and conduits).

Bar racks are best used for removal of large debris varying in size from logs and tires to rags. Static screens can also be used to provide low intensity treatment. Screens are applied to remove smaller objects such as leaves and twigs. The aperture size can be lowered to detain smaller particles which increases the level of treatment to the point of high intensity screenings.

Land treatment methods represent low intensity treatment. The most commonly used one is wetland discharge. Wetlands provide physical-biological treatment through detaining water in biologically active areas. Wetlands are best used to remove suspended solids, organics and fecal coliform but many seasonally become a source of some nutrients (N, P). The application of this method is controlled by climatic, land area size and topographical restrictions. For more details, see the Wetland section.

DESIGN CONSIDERATIONS

The installation costs of low intensity treatment are expected to be lower than high intensity treatment since the facilities require fewer mechanical devices and less design. The use of existing wetlands is expected to be much less expensive than the structural treatment alternative.

O & M needs will vary depending on the devise. Generally, low intensity treatment is designed to require minimal operation supervision. High levels of maintenance are still needed to remove debris and sediment from the facility and maintain removal effectiveness.

The ease of development and use depends on the treatment method. Static screens and bar racks have no moving parts and need little service beyond periodic cleaning. Floatable skimmers have been reported as very effective on oil and grease, but may actually stir up discharged water and increase turbidity and suspended solids concentration. The use of wetlands requires presettling to prevent overloading with sediments and other chemical pollutants (metals, organics) which might be toxic to vegetation.

HIGH INTENSITY TREATMENT

DESCRIPTION AND PURPOSE

High intensity treatment makes use of technically designed installations to remove large quantities of pollutants. These treatment methods are generally characterized as being expensive to install and operate, structurally oriented, mechanically active, and in need of a formal design, but they characteristically provide high levels of pollutant removal. High intensity treatment is designed to protect public health, safety and welfare by removing pollutants when the runoff concentration exceeds federal, state and local water quality standards. Because these means of treatment are generally not used in nonpoint pollution control, only a brief information summary will be presented.

TARGET APPLICATIONS

The target pollutants vary depending on the treatment facility design. Generally, physical treatment is aimed at removing settleable solids and suspended solids; chemical treatment removes suspended solids and fecal coliforms (pathogen indicator); and biological treatment removes organic materials. As previously stated, many pollutants associated with the target pollutants are removed as a result of primary pollutant treatment.

High intensity treatment methods are not commonly applied to nonpoint source pollution. These methods are usually reserved for sanitary sewage effluent, but are also routinely applied to combined sewer overflows. High intensity treatment is applied when polluted water discharging into a watercourse represents a health hazard or water quality hazard and cannot be adequately controlled by a nonstructural alternative. They are usually applied to areas that have an existing combined or separated sewer system which is experiencing overflow problems.

EFFECTIVENESS

Treatment methods are generally highly effective ways to improve water quality by removing pollutants. The actual effectiveness of each treatment method will vary with facility design, loading factors, and detention time. The following removal efficiencies were collected from a variety of sources (Lager et al., 1977; Oberts, 1980); they are provided to give a general idea of the method's effectiveness on different pollutants. Since much of the data were determined from tests on sewage treatment plants, efficiencies of runoff water treatment may vary, and will likely be lower because of high loading rates and biological impact.

	Pollutant Removal Effectiveness (Percent Reduction)					
Treatment Method	SS	BOD_5	COD	TN	TP	Fecal Coliform
Swirl Concentrator	40-60	25-60	--	--	--	--
Screening						
Microscreen	50-95	10-50	35	--	20	--
Drum screen	30-55	10-40	25	--	10	--
Rotary screen	20-35	1-30	15	--	12	--
Disc screen	10-45	5-20	15	--	--	--
Static screen	5-25	0-20	13	--	10	--
Sedimentation						
With chemicals	68	68	45	--	--	--
Without chemicals	20-60	30	34	--	20	--
Dissolved Air Floatation						
With chemicals	70-90	42-57	45	17	69-70	--
Without chemicals	56-69	26-40	41	14	0-16	--
Filtration	70-100	44-93	35	--	90-95	--
Clarification	--	90-98	--	--	80-90	--
Disinfection	--	--	--	--	--	99+
Contact Stabilization	92	83	80	50	50	83-91
Trickling Filter	85-95	85-95	--	0	0	--
Rotating Biological Contactors	60-95	60-90	70+	40	50	--
Treatment Lagoons	50	--	40	--	--	90
Oxidation ponds	50-60	10-70	--	56	40	86
Aerated lagoons	74-95	75-95	--	--	--	--
Facultative lagoon	50	50-90	--	62	69	96

PLANNING CONSIDERATIONS

High intensity treatment is generally reserved for water containing sanitary sewage. To apply one of these treatment methods to a nontoxic, nonhazardous,nonpoint source pollution would not likely be cost effective unless a significant problem needed to be addressed. Treatment facilities require a specific engineering design. Factors such as the period of operation, operating costs and requirements, treatment response time, required efficiency, and major targeted pollutants should be evaluated when designing the treatment facility.

There are three types of treatment--physical, chemical and biological. Treatment facilities commonly use a combination of methods. Physical-chemical systems represent a compatible combination which acts to increase removal effectiveness, as follows:

Parameter	Removal Efficiency
BOD_5	90-97%
COD	75-96
TOC	74-94
TSS	85-99+
TP	90-99
TN	45-98
Fecal Coliforms	99+
Turbidity	85-99+

*Processes: chemical clarification, chemical recovery, filtration, carbon absorption, activated carbon regeneration.

Physical treatment methods provide both high and low intensity treatment. These methods physically remove pollutants. Typical physical treatment methods include settling, screening, filtration, dissolved air floatation and swirl regulator/separators.

Settling--A detention basin can be used to provide primary settling. Settling is the removal of suspended particles through gravity. Settling can be enhanced through chemical flocculation. Settling methods have a disadvantage of requiring large land areas and long detention times.

Screening--Urban wastewater can be directed through various sized screens. Screens are often applied in series in order of decreasing size. This method is generally effective for removing coarse and medium-sized particles. It is not effective at reducing fine particles or organics. The advantages are that screens require little space, are easy to operate and combine well with other treatment methods. High intensity screening methods include small aperture static screens, microscreens, drum screens, rotary screens and disc screens.

Filtration--Suspended matter is separated as water is passed through a porous medium. Typical medium materials include sand, finely woven fabric, stone, plastic or coal. Filtration provides high treatment efficiencies, has low land requirements and can be designed for automatic operation.

Dissolved Air Floatation--Injected air bubbles adsorb to particulate matter and raise it to the water surface of the detention area where they may be removed by skimming. The advantages are that it requires a short detention time; it is an effective remover of solids, phosphorous and oxygen-demanding materials; and it is easy to operate. The disadvantages are that it requires a large land area and it is not effective at removing oil and grease.

Swirl Regulator/Separator--In this case wastewater is treated by a swirling action and liquid/solid separation occurs while flow is regulated by a central circular weir spillway. The advantages are an absence of primary mechanical parts, automatic control and effective removal of floatables and settleable solids. Difficulties include problems in removing organics and nutrients, and large space requirements.

Chemical treatment is usually applied in addition to physical treatment methods. Chemicals are applied to assist with clarification and disinfection.

Clarification--The addition of chemicals (Fe or Al salts) promotes flocculation by forming coagulated particles that settle out. Coagulation/flocculation is considered to be effective at reducing organics, sediments and heavy metals, and, to a limited extent, nutrients and oxygen-demanding substances.

Disinfection--The most common method of disinfection requires the addition of some form of chlorine (sodium hypochlorite, calcum hypoclorite) that will destroy pathogenic organisms. The chlorine dosage must be adjusted within the recommended acceptable range of free available chlorine residual.

Biological treatment utilizes biological conversion of organic matter to form cells that can be removed by gravity settling. Biological treatment removes nonsettleable colloidal solids and stabilizes dissolved organic matter. Biological systems are not often applied to urban runoff since the biomass is difficult to maintain during erratic and often toxic, loading. Commonly applied biological systems include contact stabilization, high rate trickling filtration, rotating biological contactors and treatment lagoons.

Contact Stabilitation--In this method activated sludge is mixed with water and aerated. After settling, concentrated sludge is aerated and part of the sludge is recycled to the contact basin to be mixed with the new inflow. It is effective at removing SS and BOD_5, but is expensive to build and operate.

Trickling Filters--This method involves large circular tanks which are filled with a filter medium to provide a surface for biological slime to grow. Organics are removed through absorption by the slime which periodically sloughs off leaving a surface for further slime growth. This method can be designed to handle variable flows by changing the loading rate. Trickle filters are effective at TSS and BOD removal, but provide no significant removal of nutrients.

Rotating Biological Contactors--This contactor is a cross between a trickling filter and an activated sludge system. Biomass grows on a large rotating disc which absorbs organics while exposed to runoff water. Removal efficiencies are a function of the contact time, and are generally quite good.

Treatment Lagoons--Oxidation ponds, aerated lagoons, facultative lagoons and anaerobic lagoons are the basic types of biological lagoon treatment. Oxidation ponds utilize algae and bacteria to remove BOD and TSS. Oxygen is supplied by the algae to maintain an aerobic environment. Algae and bacteria must remain balanced to keep the environment at maximum effectiveness. Removal efficiencies vary depending on loading, detention time, oxygen supply and mixing. The disadvantage is a requirement for long detention times.

Aerated lagoons are the same as oxidation ponds except that the oxygen is supplied mechanically. They are frequently applied as a series of ponds. Facultative lagoons utilize three layers. The upper aerobic zone oxidizes suspended solids and is frequently artifically aerated to maintain the proper environmental balance. The middle zone is a facultative or transition area. The lower zone is anaerobic and provides stabilization of settled materials. Anaerobic lagoons cannot be applied for treatment of stormwater runoff because of the variable flow and loading factors.

DESIGN CONSIDERATIONS

High intensity treatment information is generally derived from studies on combined and separated sewer flows. The cost information has been determined for specific treatment applications and will vary when applied under different situations, combinations and loadings. Cost information on existing treatment facilities has been compiled in Oberts (1980) and Stanley Consultants (1976). The variability of stormwater flow creates difficulties when applying intensive treatment methods. In some cases facilities operate only during storm events. Facilities not utilized during dry weather represent a loss in capital investment.

Physical treatment is generally easy to adapt to varying flows associated with nonpoint source runoff. Chemical treatment is valuable as a method of eliminating pathogenic organisms and improving physical clarification. Chemical treatment is rarely applied unless in combination with another method. Biological systems are effective at removing waste, but are difficult to apply to urban runoff. Urban runoff may wash away the biomass or kill it with toxic chemicals (heavy metals, organics, road salt). Biological systems are also difficult to maintain during fluctuating flow rates.

Generally O & M needs are high. High intensity treatment requires highly technical designs. In most cases, a trained operator is needed to maintain the system. Some systems can be simplified or designed to provide automatic operation, but they still require maintenance to keep the system operating properly. High intensity treatment systems are usually applied in connection with a sewer line, with O & M being the responsibility of the public utility.

PART B. AGRICULTURE

INFORMATION AND EDUCATION

DESCRIPTION AND PURPOSE

Information and education programs are an essential part of a successful nonpoint source management program. Education programs encourage voluntary nonpoint source pollution control by providing better awareness of pollution problems, control alternatives and implementation considerations.

The first goal of an education program is to convince the landowner that a problem exists. In a 1981 survey (Journal of Soil and Water Conservation, 1983) of farmers in Ontario, response indicated that erosion was not viewed as a severe problem. Only 26 percent believed sheet erosion was very severe to extremely severe, 37 percent thought it was of minor severity, while 37 percent did not respond.

In a Pollution From Land Use Activities Reference Group (PLUARG) Canadian agricultural survey (IJC, 1978) 80 percent of the farmers responded that farming activities had little or no effect on water pollution and 90 percent believed their present management practices were adequate. However, 72 percent were interested in receiving more information relating to control of water pollution from farming activities.

An Illinois farmer attitude survey (Seitz et al., 1978) found farmers recognized the value of soil conservation; 76 percent of those surveyed thought soil conservation was needed to maintain soil productivity, while 69 percent responded it was needed to maintain water quality, however this does not indicate that they use adequate control measures. Because sheet erosion is difficult to see, many farmers may not be aware of the extent of soil loss or the overall effect on water quality. Education programs are needed to illustrate the magnitude of the problem and how soil loss affects fertility as well as water quality.

Once a landowner is aware that a nonpoint source pollution problem exists, information is needed to introduce pollution control solutions. Education introduces various control techniques, from better chemical applications to conservation tillage and grassed waterways. As a persuasion method, education programs are used to indicate the benefits to the farmer which may include reduced production cost, maintained soil productivity and protection of a natural resource.

Education programs are needed to provide implementation consideration information. They provide the information needed to determine which management practice (MP) best meets a particular area's needs. Technical assistance is available to show how to use a chosen MP to provide the best production and protection against crop failure. Information on the cost of an MP, net profit or financial assistance should be available through education-information programs.

TARGET APPLICATIONS

Information and educations programs are aimed at controlling all pollutants by promoting awareness and acceptance of agricultural MPs. The major pollutant from agricultural land is sediment, though organic matter, nutrients and pesticides transported by runoff also affect surface water quality.

Information and education programs represent a broad range of programs that can be targeted at a specific group of people or the general public. Programs should be organized to provide information to anyone interested. Areas having critical erosion problems may require more intensive methods to persuade farmers of the need for nonpoint source controls. Educational programs should not be limited to farmers and agricultural landowners. Government agency personnel and politicians should all be exposed to the problems with agricultural nonpoint pollution, since these groups make policy decisions that will affect landowners and the attractiveness of applying MPs.

EFFECTIVENESS

The effect of a well planned information-education program on water quality cannot be quantified, but it is considered to be an effective method of promoting the use of other MPs that protect water quality. Information, education and technical assistance do not directly affect water quality, but provide awareness of the problem, acceptance of a solution and methods to achieve the solution, which ultimately results in improved water quality. Education depends on voluntary cooperation, therefore, its effectiveness is dependent on how well the program deals with each individual farmer´s concerns and needs. The most effective information source is a comprehensive local program which uses all channels of communication including informal meetings and personal contact.

PLANNING CONSIDERATIONS

Education, information and technical assistance programs are important components for developing a nonpoint source management plan. These programs help control agricultural pollution by creating awareness and developing a solution. They provide information on economic considerations, new control technology, implementation considerations and farmer, as well as community, benefits.

Various agencies have developed educational programs aimed at agricultural pollution control. To assure the best information network, these agencies should coordinate their efforts. The USDA Cooperative Extension Program provides information and promotes awareness of nonpoint source problems. The Soil Conservation Service (SCS) works at problem solving by providing technical assistance in application of control measures. Local soil and water conservation districts provide management aid, technical expertise and are in a position to help direct other agency programs such as USDA-SCS and ASCS, according to local needs.

An information and education program is best used when it is organized according to local needs. The success of an educational program will depend on how well it addresses the concerns of the farmers. That is why it is important to organize programs using local farmer input to determine the economic, technical, environmental and psychological considerations.

Most farm decisions center around economics as a major factor. Farmers may be concerned about soil loss and pollution but unless the control method is economical, they will not implement it. Education may have to be aimed at removing psychological attitudes that may prevent the use of a control technique because of previously learned behavior. For instance, some farmers have difficulty accepting no-till or reduced fill if they were taught that leaving residues implies poor farming.

Acceptance of control meaures may depend on the information source. Education programs from agencies that already have a working relationship with farmers may be received better. Especially agencies that have in the past helped provide technologies which increased yields or profits. Perhaps the most effective education source is the use of an informal information network. The most convincing salesmen being farmers that have had good experience with nonpoint source control methods such as no-till or contouring.

Information is needed to choose conservation practices according to land needs and capabilitites. Applying an MP on land that is incompatible with the practice or not using it correctly may cause disasterous results, which discourage the landowner from continuing the use of pollution control practices or from trying better suited methods. The availability of adequate technical assistance after a landowner is persuaded to try a control method is necessary to insure proper application.

The following education programs can be used to provide information on agricultural nonpoint source pollution:

- Presentation, educational training, workshops, classes, lectures, slide programs and seminars that provide information on topics such as pest management and soil conservation.
- Exhibitions, such as fair exhibits, that present of soil conservation methods, machinery and information.
- Planting demonstrations, demonstration plots, field tours that provide first-hand view of various conservation methods.
- Publications, pamphlets, brochures, newsletters that provide updated information.
- Media, radio, television, press releases, magazine articles that promote awareness.
- Public meetings, personal contact by agency technical staff and pro-conservation neighbors or organizations.

DESIGN CONSIDERATIONS

A well organized, effective education program is not easy to develop. The program will be more effective if designed to deal with the concerns of local farmers. Because most education programs are persuasion methods aimed at promoting the voluntary use of agricultural nonpoint source pollution controls, the effectiveness cannot be guaranteed. A program should not be difficult to implement since existing agencies could be designated to expand their existing education, information or technical assistance programs.

The cost of expanding the present education system includes acquiring trained technical staff, education materials and supporting staff. By using an existing agency such as the county extension service, SCS or SWCDs, costs can be reduced. The actual cost of implementing nonpoint source pollution controls is the responsibility of the farmer or some government agencies if financial assistance (tax credit, cost sharing) is available. Spending taxpayer dollars on education is a way to control the source of pollution. Alternatively taxpayers could pay for the resulting surface water quality problems originating from agriculture pollutants. These costs are usually higher and include dredging sediment from ditches, rivers and reservoirs and increased cleaning costs for downsream water users.

One study (Seitz et al., 1978) calculated costs by assuming 1,221 farms per county and 93 counties per state. Prices were determined by averaging 1976 values from the cornbelt states; Illinois, Indiana, Iowa, Minnesota, Missouri, Nebraska, Ohio and Wisconsin. Estimated annual county level administrative costs for a five-year education program was $162,600 annually, a seemingly high cost but small when compared to the cost of implementing management practice solutions. The Metropolitan Council 1982 Nonpoint Source Pollution Technical Report (Oberts, 1982) estimated the cost of an information education program for rural lakeshore owners to be between $1,000-$5,000 per lake.

CHEMICAL MANAGEMENT

DESCRIPTION AND PURPOSE

Chemicals are used in agriculture to increase crop production and control pest infestations. Fertilizers applied to provide nutrients for crops contain either nitrogen or phosphorus. Pesticides most commonly used in agriculture include insecticides (insects) and herbicides (weeds). Chemical management is the organization of a chemical use plan that reduces the chemical impact on water quality by controlling chemical application or transportation methods. Chemical management should increase controls on chemical use while continuing to meet cropland needs. Chemical management techniques include: soil conservation, alternative control, optimized application and integrated control.

Soil conservation uses cropping and tillage practices to control runoff and erosion. The use of conservation methods reduces chemical and sediment movement from the site of application. Alternative control uses different less toxic chemicals, nonchemical supplements, biological or mechanical controls to maintain high crop yields without pesticide or nutrient applications. Optimized applications reduce chemical losses by controlling the source. Eliminating excess use and better timing, placement and application methods results in less chemicals available for transportation to runoff, more chemical available to the crop and economic benefit to the farmer. "Integrated pest management" control is a comprehensive plan which uses a combination of techniques to protect crops. Concepts encouraged by this method are scouting and need-based application. Reduced chemical application should result in an improvement of surface water quality.

TARGET APPLICATIONS

The target pollutants are chemicals commonly used on agriculture land; specifically nutrients (phosphorus, nitrogen) and pesticides (insecticide, herbicide). For a specific list of chemicals used in agriculture see USDA-ARS (1975) and Metropolitan Council (1981).

Chemical management should be used for all agricultural chemical applications. Agricultural land is the highest nonpoint source contributor of suspended solids, nitrogen and phosphorus in the Metropolitan Area (Metropolitan Council, 1982). The extent of chemical management needed will depend on the surrounding environment and chemical properties.

Controlling the transportation of chemicals from the application site protects water quality. Chemical movement results in the unavailability of chemicals for the intended purpose as well as polluted surface water and groundwater. Chemicals are transported by wind drift, runoff, seepage or volatilization. The transport method that has the most impact on surface waters is overland runoff, with chemicals in solution or adsorbed to sediments. Actual chemical movement varies greatly according to the surrounding environment. Environmental factors that influence chemical loss and transportation to a waterway include: land characteristics and use, topography (slope, drainage), soil type (structure, moisture level, erosion rate), distance to surface water, climate, precipitation (quantity, frequency, intensity), snow cover, type of crop and tillage practice. The physical and chemical properties of a nutrient or pesticide will control the use of a specific management technique. A chemical's impact on the environment is a function of its solubility, toxicity, persistence and mobility.

Nutrient management is used when large quantities are present in overland runoff. Nutrients are most frequently applied according to manufacturer recommendations, which frequently results in overuse. Using soil tests to determine when nutrients are needed should significantly reduce applications and subsequent transportation in runoff. The two nutrients of concern, phosphorus and nitrogen, have different properties. Most applied nitrogen is highly soluble and is difficult to control with soil conservation methods. Water with high nitrate concentrations, however, has the potential for denitrification, so nitrogen is not an extremely persistent chemical. High nitrate levels are considered toxic for infants under three months of age. Phosphorus can be highly mobile in a dissolved or adsorbed form. Phosphorus is commonly the limiting agent for aquatic weeds and algae. Increases in phosphorus are usually responsible for eutrophication, resulting in aesthetic and water quality deterioration.

Pesticide management is complicated by the wide variety of chemical compounds. When practical, pesticides should be applied only when there is a pest problem that will cause an economically significant quantity of damage. Pesticide properties vary widely depending on the compound and formulation. Additional controls should be used when dealing with a chemical which is highly toxic, persistent or very mobile.

EFFECTIVENESS

Chemical management utilizes many techniques to protect surface water from agricultural chemical use. Water quality is protected by reducing chemical use, or controlling transportation off-site. The effectiveness of chemical management on protecting water quality is dependent on the management technique and the site. Variations in annual data due to climate make it difficult to determine the actual effectiveness of a specific management technique. Fertilizer and pesticide management may reduce nutrient and pesticide pollution up to 50 percent (Oberts, 1982).

The effects of soil conservation on reducing chemical pollution of surface waters varies with the tillage method and the chemical. Soil conservation methods are generally considered highly effective at detaining adsorbed chemicals, but are less effective for controlling soluble chemicals such as most pesticides. Conservation tillage which reduces runoff may contribute higher levels of chemicals because of lack of incorporation or higher use rates. The following table shows how various tillage practices can influence water quality in an Iowa example (Haith and Loehr, 1979):

	Tillage Practice* (Percent Change)				
	Conventional	Contouring	Terracing	Sod Rotation	Conservation
Runoff	0	-15	-30	-55	-30
Percolation	0	+ 5	+ 5	+10	+10
Sediment	0	-55	-95	-60	-70
Nitrogen					
dissolved in runoff	0	-25	-30	-75	-30
dissolved in percolation	0	+10	+10	-50	+10
solid-phase in runoff	0	-55	-95	-60	-70
Phosphorus					
dissolved in runoff	0	-20	-30	-55	-35
solid-phase in runoff	0	-55	-95	-60	-90

*Rounded to nearest 5 percent. 25-year simulation model using Iowa data.

Alternative methods wherein pests are controlled without pesticide applications are generally highly effective. Destroying pest host plants has been credited with reducing up to 95 percent of pest populations (Metropolitan Council, 1981). Eliminating chemical use will provide 100 percent reduction in associated chemical transport to a waterway. Optimizing application procedures should be relatively effective at controlling chemical losses to surface waters. For different pesticides, changing application procedures may provide a 0-25 percent reduction in toxic materials (IJC, 1977).

Integrated pest management programs are considered very effective at controlling pesticide use. Programs for major crops may reduce pesticide use up to 75 percent as well as reduce preharvest pest losses by 50 percent (U.S. EPA, 1980). The reduction in pesticide use is expected to provide a substantial reduction in chemical losses to surface waters as well as a reduction in pest control costs.

PLANNING CONSIDERATIONS

Chemical management utilizes many different techniques to control chemical contamination of surface waters. Chemicals can be controlled at the source, since the best method of reducing a chemical´s contamination of water is to reduce or eliminate that chemical´s use. The second method is to control the chemicals´ movement to a water body. Movement may be reduced by either controlling the method of transport (erosion, runoff) or eliminating a chemicals susceptability to movement (improved placement or timing).

Soil conservation practices are designed to control transport modes, that is erosion and runoff, rather than institute direct management of potential pollutants such as nutrients or chemicals. The best method for controlling adsorbent or solid phase chemicals is to control sediment transport. Residue management cultivation such as conservation tillage or no-till reduce erosion, sediment movement and associated chemical transportation. Soluble chemicals are best controlled by practices such as terracing or contouring which control runoff. By increasing infiltration and retention, less runoff and dissolved chemicals enter surface waters.

The actual effect that a soil conservation practice has on agricultural chemical losses from croplands is site-specific and depenedent on the chemical´s proerties. The site characteristics, climate, soil and land contours will affect the success of applying soil conservation to control chemicals. Chemical properties, particularly solubility are important when choosing an effective control. For instance, conservation tillage would control phosphorous which is extremely adsorbant, but not nitrogen which tends to be highly soluble. In most cases soil conservation practices reduce the amount of chemicals entering surface waters with the exception of reduced tillage methods where chemical application increases might be greater than reductions in erosion and runoff.

Alternative controls provide substitute methods of controlling pests or supplying nutrients that reduce or eliminate the need for pesticides or fertilizers. Alternative controls that can be used include alternative chemicals, alternative cropping practices and biological control. Alternative chemicals may be able to control pests or supply nutrients without contaminatng water supplies. The proper selection of a chemical can result in lower transport rates to surface waters while providing better control. The chemical formulation should be chosen to provide the best protection while being relatively resistant to transport.

Nutrients can be applied as granular, gaseous or liquid fertilizers. The fertilizer should be in a form that will not be washed away easily. Various forms are available, for instance nitrogen fertilizer can be based on ammonia or nitrate. An alternative slow release fertilizer compound reduces nitrogen losses due to leaching. Chemical inhibitors delay nitrification resulting in longer crop utilization of a single nitrogen application. Slow release fertilizers are limited to use on plants with long growing seasons. They may continue to provide available nitrogen after the growing season, potentially resulting in high levels of nutrients in runoff after the growing season.

In many cases several interchangeable chemicals could be applied to control a specific pest. The properties of a pesticide should be considered to maximize efficiency while minimizing the environmental impact. A pesticide´s properties will vary with brand and formulation. The major properties that control effect on water quality are adsorption and solubility. The best pesticide can be determined by considering site characteristics and pesticide properties. For example, an area subjected to heavy rainfall but little erosion would need an adsorbant pesticide. Mobility, toxicity, persistence and transport mode should also be considered when choosing the best pesticide.

The pesticide formulation may be altered to change pesticide properties. For instance, granular forms may be less prone to transport than liquids. Pesticide components, solvents, additives or dilutents can be altered to improve penetration which allows a reduction in active chemical quantities. Another reason for using alternative chemicals besides lowering the accumulation level of a specific chemical in the environment is the reduction in the probability of a pest species developing immunity to a commonly used chemical.

Pest resistant crops can be cultivated to reduce the need for pesticides. They provide persistent protection from a specific pest population which reduces the crop losses without damaging the environment. Development of resistant crops requires extensive research, time and money. Development of resistant species are usually limited to crops and pests where a success will result in large economic benefits. Resistant crops are best used when a specific insect is causing extensive damage. Breeding of a crop variety that can compete with weeds has not been very successful.

Legumes can supply nitrogen to the soil by creating organic nitrogen compounds from atmospheric nitrogen. Legumes such as red clover, alfalfa and soy beans can be planted to place nitrogen in the soil. Legumes are often planted in rotation so that nitrogen will be provided for next year's crop. A legume crop can be grown and plowed under to condition the soil for future crops. The results may include higher yields next year and lower fertilizer needs but this rarely compensates for having the field out of production. Alternatively legume crops can be harvested for livestock feed or planted in hayfields or pastures. Using a legume-grass mix reduces the need for nitrogen applications since legumes supply the needs of the grass.

Crop rotation can result in a decrease of chemical transport to surface waters by decreasing runoff and reducing the chemical quantities applied. Crops should be rotated between varieties that are compatible with each other, can grow in the specific climate and soil, and are economically profitable. Altering crops with legumes reduces the need for nitrogen applications and sod rotations reduce runoff. Rotations control insects by interfering with their life cycle and removing host plants, and allows a reduction in herbicide use for weeds that are easier to control in specific crops.

Cultivation of crops can be altered to provide nonchemical control of pests. Altered cultivation practices do not eliminate the need for chemicals but may reduce the application rate. Timing of crop cultivation can influence the concentration of pest population. In northern states the corn earworm will cause less damage to early planted corn while later planting combats damage by white grubs and seed maggots. Optimized timing is applicable to many crops and is based on crop, insect characteristics and climate.

Mechanical control of weeds is an alternative to chemical control. Commonly used mechanical controls include hand pulling and machine mowing or cutting. Mechanical controls may result in increased erosion, soil compaction and moisture loss. They are also not extremely effective once a crop has been planted, so chemicals are usually used to supplement mechanical controls.

Biological control is the use of biological manipulation to control pests. Biological cotrols cover a wide range of techniques including insect attractants (fluorescent light rings, sex attractants), insect diseases, pest sterilization, genetic changes, and pest predators. Biological controls are not widely used since they are difficult and time consuming to develop. Existing controls have limited applicablility, but the few cases where it has been applied demonstrates the effectiveness and possibility of eliminating the need for pesticides.

Optimized applications should result in a reduction of chemicals available for transportation to a surface water. It is in the best interest of farmers to optimize chemical use since chemicals transported from croplands do not benefit the crops. Chemical users should consider the following concerns: quantity, timing, placement, application methods, storage and disposal.

The most direct method of reducing the quantity of agriculturally used chemicals in surface waters is to reduce the application rate. Decreasing fertilizer and pesticide quantities result in a cost savings to the farmer as well as decreased risk of water pollution. Both nutrients and pesticides have been subjected to over use. Soil tests to determine fertilizer needs may be considered inconvenient but the savings on fertilizer costs will often make testing economically worthwhile. Use recommendations on pesticide labels are developed on a nationwide basis, therefore, in a specific area lower application rates may be sufficient to control the target pest. Alternative chemical application rates can be recommended by the appropriate state or county agency.

Insecticides are often applied to prevent insect outbreaks, which result in unnecessary applications. Insects which remain underground are difficult to treat on a crop damage basis since infestations are difficult to discover and control before damage occurs. However, applying chemicals to control above ground insects may be based on plant damage and pest populations. By using chemicals only when needed, a reduction in quantity will save pesticide costs and reduce impact on surface water.

The quantity of applied chemicals can be reduced by implementing more efficient formulations. For instance using low volume concentrated sprays allow fewer applications that reduce insecticide use and maintain the same level of pest control. Herbicides diluted with vegetable oil are more effective at remaining on target plants, therefore, reduced quantities can be applied.

Optimizing the timing of chemical applications may result in increased crop yields and reduced chemical transport from the field. Crop yields increase when nutrient additions are matched with crop needs or when pesticide applications are timed to when they most effectively eliminate pests. Chemical losses from the fields can be reduced by timing applications with precipitation events that provide the transport mode and field operations where incorporation into the soil reduces exposure to erosive forces.

The best data for applying a chemical should be chosen after considering crop needs, chemical properties, season and weather. A crop´s chemical needs are an important factor in timing the application. Nutrient applications should be timed according to need. Nutrients which are applied too soon may be transported away from the root zone before the plants can utilize it, especially nitrogen which is susceptible to leaching. Late nutrient applications may result in lowered crop yields. Pesticide applications are frequently most effective at a critical growth stage. The pesticide application should be timed so it will be available when it is needed, which is frequently early spring.

The season is an important factor in timing chemical applications. Nutrients are best applied in the fall or spring, depending on the soil, climate and crop. Chemicals should not be applied to frozen ground or to bare ground just prior to stormy weather. Pesticides can be applied as pre-plant, pre-emergence or post-emergence treatments. Treatment timing depends mostly on the target pest. The best time for pesticide application is usually in the spring, unfortunately this is also the period of highest chemical losses due to lack of foliage and high precipitation quantities. The largest quantities of pesticide losses usually occur during the first heavy rainfall and runoff after application (Oberts, 1982). Timing applications to provide the maximum time period before precipitation may help control runoff losses.

The placement of a chemical will effect the contamination of runoff water. Chemicals should not be applied to locations such as steep slopes, or buffer strips surrounding a waterway. These critical areas are particularly susceptible to chemical losses due to erosion or runoff. The placement of a chemical within the soil will control its effectiveness and loss from the field. The placement will depend on the crop tillage practice. Spray applications of pesticides are subject to drift and volatilization. To provide the best placement of pesticides by spraying, special nozzles or low pressure may be used. Difficulties with placement of spray applications discourages their use during high wind or temperature inversions. Spray application losses are difficult to control though their use is required in several situations.

The placement of ground applied chemicals is an important method of controlling losses from the field. To prevent chemicals on the surface from being washed away by erosion or runoff, applications are incorporated into the soil. The most common method is to broadcast the chemical and then plow it under. Incorporated chemicals are not available for transportation by surface modes unless erosion of the soil occurs. Plowing under benefits crops by providing better distribution of the chemicals. For example, nutrients are placed closer to the seed or root system. Of course, disking a chemical is not always practical. Top dressing is necesary when applying chemicals to estabilshed pastures or some foliage crops.

Placement is particularly difficult for conservation tillage which limits incorporation. Special application procedures can be used to place chemicals in a band under the surface. Chemicals can be applied by strip placement, deep placement or directly to the seed furrow in row crops. Better placement of chemicals may require additional equipment, but increased application costs are expected to be offset by increased yields and decreased chemical losses to waterways from better chemical utilization.

The application method effects the chemical concentration in the soil and chemical contamination of surrounding waterways. Chemical losses may be reduced by changing the application procedures. Eliminating careless handling, misuse and spillage will reduce unnecessary surface water contamination. The choice of applicaton methods should match tillage practice, crop and chemical properties. Chemicals can be broadcast, injected, strip applied, top dressed, sprayed, disked and plowed under. For the best use of a specific method the equipment should be designed to provide the most effective coverage with the smallest chemical quantity.

Using proper storage and disposal methods will reduce unnecessary chemical losses. Storage and disposal requirements are listed on pesticide labels. Chemicals should not be stored in leaky containers or near water or feed supplies. If chemical containers must be changed, the original label should be kept attached with the chemical. Containers should not be left unattended in the fields or by surface waters. Other instructions on the label should be followed.

Chemical containers must be disposed of by methods allowed under the Federal Environmental Pesticide Control Act of 1972 (Public Law No. 92-516) (USDA-ARS, 1975). The best disposal method for pesticides is to bury containers in an approved landfill. The containers should be rinsed and punctured before disposal and rinsings should be applied to the field or buried with the container.

"Integrated pest management" programs combine a variety of techniques for the benefit of croplands. Integrated mangement systems do not eliminate the use of chemicals but utilize alternative control methods as well as chemicals in a comprehensive plan. Integrated systems require a wide knowledge of alternative controls and crop needs. Integrated pest management programs use knowledge of the target pest species, chemicals and alternative controls to economically control pests with the least damage to the environment. The basic approach is not to eliminate pests, but to monitor crops and apply controls to retain pest populations at tolerable levels.

Implementation of integrated pest management requires effective planning. Planning requires data on the problem pest such as natural enemies and environmental controls. Cropping methods and initial chemical treatments are applied as primary teatment, but integrated pest control relies heavily on monitoring to control localized pest outbreaks instead of applying preventative chemicals. "Scouting" is population monitoring used to determine when additional chemicals are needed to control pest concentrations capable of causing economic damage to the crop.

The EPA is legally responsible for regulating pesticides that create unreasonable damage to human health or the environment. Commercial pesticides must all be registered with EPA. To be registered the manufacturer must supply data proving that new pesticides will not have a harmful impact. Regulations are applied when a chemical may create a health hazard or damage the environment. Regulations are made by considering the chemical effects on agriculture, public health, environment and economic benefits. EPA regulates pesticides use further by requiring labelling which instructs users on proper use, storage and container disposal procedures approved by law. EPA regulates pesticides in an attempt to remove harmful products from the market and promote proper handling practices. The full impact of a chemical is not always known, so that constant environmental monitoring is required to prevent water contamination. For example, organochlorine insecticides, such as DDT, were banned because of their persistence and ability to accumulate in acquatic organisms.

Most herbicides are not persistent and are not considered critically toxic chemicals for humans. Appliers of herbicides have up to four times the chromosome aberrations as people in a control population (Jour. S & WC, 1983), but studies have not conclusively proven the effects of herbicides on people. Presently, few herbicides have limiting regulatory criteria; however, additional regulations may be needed for specific herbicides if chronic problems develop.

Nutrients have limited controls since they do not create a critical health hazard. Use is generally left up to the discretion of the user with recommendations listed on the fertilizer label. The use of fertilizer management controls is strongly suggested, particularly application of fertilizer according to need as indicated by soil tests.

While chemicals are regulated during production and distribution, the application of chemical management principles remains optional. Eductional programs are needed to provide technical information and to encourage use by providing information on the economic and environmental benefits of applying various chemical management systems.

DESIGN CONSIDERATIONS

Chemical management principles include soil conservation, alternative control methods, optimized application and integrated control. The development and use of any one of these principles requires an understanding of the interaction between control methods, chemicals and environment. Education and technical assistance are frequently available to interested individuals through various government sponsored programs.

Soil conservation practices use alternative cultivation and tillage practices. The use of some soil conservation cultivation methods, such as terracing, require structural changes. Difficulties when using chemicals with conservation tillage occur during application, distribution and availability. Change in tillage methods, such as conservation tillage, may require special equipment.

Reduced tillage systems may require higher applications of chemicals to control weeds and insects when incorporation of chemicals into the soils is limited. Broadcasting chemicals on the soil surface may be ineffective if the surface crop residue associated with some tillage methods prevents chemicals from reaching the soil surface. In some cases, the difficulties result in an overall increase in chemical pollution of surface waters.

The costs of various tillage systems will change depending on several factors. Generally, herbicide and fertilizer costs increase as tillage decreases. Depending on the site, crop yeilds may increase or decrease from conventional tillage production. The following table lists the 1978 costs per acre by tillage practice in the Western Lake Erie Basin (Hemmer and Forster, 1978):

Tillage Practice	Tillage	Herbicide	Fertilizer	Total
Conventional	$19.13	$14.17	$55.58	$88.88
Chisel Plow	14.79	14.41	52.69	81.89
Minimum Till	11.00	14.38	64.42	89.80
No Till	0.00	25.08	59.82	84.90

*1978 figures.

The ease of development and use depends on the extent which the alternative chemical must be different. Using an alternative formulation of the same chemical is not that difficult, though the formulation change can substantially raise resistance to movement. However, finding a different chemical that has comparable effectiveness and cost may be more difficult. Interchanging chemicals requires knowledge of chemical costs, impacts and effectiveness.

Additional costs may occur if the form is changed and a different type of application equipment is necessary. Costs of special chemicals, such as slow release fertilizers, are prohibitively higher, but further research and development may result in a better controlled and more economical alternative for use in the future.

The disadvantages of applying alternative cropping practices vary with the specific control method. Developing resistant crop varieties requires time and money to conduct research. Crop resistance is rarely adequate to completely control pests so reduced rates of chemical application may still be required. Research is conducted by federal or state agencies or by private companies. The cost of financing research on resistant crop varieties is high, though the returns in reduced insect damage and decreased pesticide costs and environmental impacts compensates for the initial expenditure.

The difficulties of using legume crops to supply nitrogen needs and reduce leaching of nitrates are site specific. Legumes do not adapt well to all soils and climates. Legume-grass fields may be difficult to maintain because grasses have a tendency of crowding out legumes. The cost of planting legumes is calculated as the loss of income by not cultivating a more profitable cash crop. The disadvantage of applying a crop rotation is the lost income when less profitable crops are planted. Depending on the crop varieties and field characteristics, various amounts of reduction in erosion, runoff, fertilizer use and pesticide use should provide economic and environmental benefits which help offset the costs of rotating crops.

Controlling pests by cultivation reduces the need for pesticides and the availability of pesticides for transportation to surface waters. Some methods provide erosion control as well as decreased chemical cost. The disadvantages are required knowledge of alternative cultivation practices, increased production cost, time and inconvenience. Generally, recommended planting times extend over several weeks but planting early or late may decrease yields and increase risks. For example, late planting delayed by rain would result in decreased crop yields.

Mechanical controls are relatively easy to achieve. Tillage equipment can be used to remove weeds and stubble that may shelter insects while preparing the seedbed. Using mechanical methods to control weeds once the crop is planted is less attractive since a method is needed that will not damage the crop.

Biological control is very difficult to develop and implement. Research is very expensive and time consuming, and complications arise when some difficult to control methods are used. For instance introducing a predator species or disease may harm desirable insects or plants as well as the target pest. Developing biological controls is costly but a successful control compensates for the cost. For each dollar invested a return in savings from reduced chemical treatment costs and decreased crop damage has been estimated at 30 to 1 (Metropolitan Council, 1981).

Optimizing chemical applications may require additional equipment, scheduling or knowledge. Optimizing quantities will require the development of a site-specific chemical program. Education and technical assistance may be needed to develop an optimized chemical use program. Trained people should be used to determine pesticide needs, since incorrect identification during scouting or pest surveillance could result in unchecked crop damage or unnecessary chemical applications.

Properly applied chemicals may provide crops with more accessible nutrients or better pest protection which results in higher crop yields as well as allows a decrease in chemical use. The savings in chemical costs and possible improved yields should compensate for most expenditures related to chemical use optimization.

The disadvantage of using an integrated mangement plan is the quantity of knowledge and surveillance needed for successful implementation. The use of an integrated system is more complex than applying chemicals and requires flexibility to use. The plan should be organized to cope with all needs, though miscalculations or poor management may result in economic damage to crops.

SOIL CONSERVATION

ALTERNATIVE TILLAGE

DESCRIPTION AND PURPOSE

Conservation tillage is the use of any tillage method that causes less soil erosion than conventional tillage. Conventional tillage is defined as the traditional tillage operations used on a specific crop in a specific region. These broad definitions have resulted in confusion when tillage practices are referred to as conservation or conventional.

In general, conventional tillage uses a moldboard plow to overturn previous crop residues. Moldboard plowing exposes soil to erosive forces resulting in high topsoil losses. Conservation tillage applies methods which reduce soil losses by eliminating exposure to erosive forces. The most commonly used method is to leave some amount of crop residues on the soil surface. Crop residues protect the soil surface from moving water or wind and increases infiltration. Tillage can be reduced by either tilling only a portion of the field or making fewer passes over the field. Conservation tillage methods include nonmoldboard tillage (chisel, disk), reduced tillage, sweep tillage and strip tillage. No-till places plants in a narrow slit or punched hole, therefore, tillage is not used and soil exposure is reduced by retaining crop residues and limiting soil disturbances. The principles of no-till are the same as those for conservation tillage only no-till represents an extreme compared to conservation tillage practices.

The purpose of applying conservation tillage or no-till is to reduce cropland soil losses. Controlling erosion protects the long-term cropland fertility and the water quality of surrounding surface waters. It benefits both landowners and the public to keep topsoil on croplands where it produces instead of in surface waters where it pollutes.

TARGET APPLICATIONS

The major conservation tillage and no-tillage target pollutant is sediment. Conservation tillage reduces soil losses from croplands which results in smaller quantities of sediment and associated pollutants delivered to the surface waters. Other pollutants that may be controlled by conservation tillage practices include nutrients, pesticides and organic matter.

Conservation tillage or no-tillage should be applied when high erosion rates create a significant soil loss. It is not a priority for lands that have low erosion rates and high crop yields. Several target situations that benefit from use of conservation tillage include croplands with poor vegetative cover, exposed soils subjected to heavy overland flows, soils that need moisture conserved and highly erodible soils.

Conservation tillage is best applied when field conditions will be compatible with the tillage method. Conservation tillage seems to operate best on well-drained, sloping, permeable, coarse textured, erodible soils. There are several situations when conservation tillage may not be the best choice. For instance, level, saturated, fine-textured clay soil with poor drainage may not improve water quality and might result in lower crop yields. In most cases, however, a well-managed conservation tillage field should result in reduced production costs, an improved environment and maintained, if not increased, crop yields.

EFFECTIVENESS

The effectiveness of conservation tillage at improving water quality is site specific. Fields that do not have an erosion problem will receive little benefit from conservation-oriented practices. The interaction between field characteristics (soil, slope), climate, crop and tillage application will determine the actual conservation tillage effect on water quality. The actual effectiveness for a specific tillage application is directly related to the amount of residue left on the soil surface.

Conservation tillage and no-till are generally very effective at reducing sediment losses to surface waters. The effectiveness at reducing nutrients and pesticides is much more variable. Conservation tillage and no-till are effective at controlling solid-phase and adsorbed chemicals but do not prevent surface water contamination by dissolved or fines-associated nutrients or pesticides. The following table provides the reduction ranges for various pollutants available from implementing alternative tillage practices (Haith and Loehr, 1979; Oberts, 1981):

Tillage Practice	Sediment Loss Reduction	Nutrient Reduction	Pesticide Reduction
Conventional tillage	0%	0%	0%
Conservation tillage	0 - 95+	0 - 70	Increase - 50
No-till	50 - 95+	--	Increase - 50
Reduced till	0 - 70	--	Increase - 50

PLANNING CONSIDERATIONS

Alternative tillage is used to reduce soil and water losses, without substantially reducing net profits. Commonly applied conservation tillage practices are chisel plowing, disk plowing, strip tillage, ridge tillage, plow-plant or other reduced tillage methods.

No-tillage provides the best protection against soil erosion by limiting soil disturbances and retaining the maximum amount of crop residue. No-till uses a fluted coulter or other devise to create a narrow slit directly followed by planting equipment. A second procedure is direct drill planting where planting in a punched hole allows seeding directly into the previous crop residue. No tillage requires no cultivation and limits disturbances to a single planting operation.

No-till is best used on soils with adequate crop residues to provide complete surface cover. It is most effective in dormant sod or small grain where residue provides complete coverage, but can be used on row crops, such as corn, by providing uniformly distributed residues. No-till operates well in some crop rotation plans.

The effects of no-tillage are highly dependent on interactions between field characteristics, crop and managerial practices. There are some climate and soil conditions that are not suited for no-tillage practices. The success of this method is often dependent on variable characteristics, such as weather or pest infestations. No-tillage requires more intense management than other cultivation methods. It has several inherent disadvantages that can be overcome by better management. Placement of seeds, fertilizer and pesticides are more difficult with a residue to work around. The control of pests is more complex and intense monitoring and proper chemical applications are needed to control weed and insect infestations.

Conservation tillage provides soil protection by reducing or altering tillage practices. Conservation tillage includes a wide range of techniques most of which result in crop residues left on the soil surface. Non-inversion tillage such as chisel or disk tillage cultivates the soil by stirring or mixing, thus leaving part of the crop residue on the surface. Other tillage methods include sweep cultivation which provides subsurface tillage, leaving residues undisturbed on the surface.

Tillage can be reduced in a portion of the field. In strip tillage, a band is cultivated where planting will occur while the area in between the rows remains untilled with surface residues undisturbed. Ridge planting is a version of strip tillage though a ridge is formed in which row planting occurs.

Reduced tillage involves principles of minimized disturbances as well as residue management. Limiting cultivating trips over the field reduces the disturbances. A till-plant process leaves residues on the field until immediately before planting. Residues protect against fall and thaw erosion leaving the soil vulnerable a shorter period to time.

Conservation tillage is more adaptable but less effective than no-tillage. Many of the difficulties experienced by no-till users can be controlled by proper application of an alternative conservation method. Conservation tillage provides the same type of benefits, reduced production cost and reduced soil loss, but with less effectiveness compared to no-till.

Conservation tillage can be applied to a broader range of soils and climatic conditions. Conservation tillage includes many different techniques, one of which should be appropriate for almost any situation. Conservation tillage is easier to apply and has fewer risks than no-till practices. For instance, fertilizers and pesticides can be incorporated into the soil. Better chemical placement and mechanical cultivation reduce the problems with weeds which plague no-till fields.

Crop yields from conservation tillage systems vary over a wider range than conventional systems. Depending on the tillage practice, field characteristics, soil, climate, crop and management practices, conservation tillage may produce higher or lower yields. Compared to no-till, conservation tillage results in higher crop yields, but the real comparison between production cost, crop yield and environmental benefits must be made for each site separately.

DESIGN CONSIDERATIONS

Conservation tillage and no-till practices may be difficult to use. The crop yields of both practices are related to variables that are difficult to control, that is, weather and pest problems. Some difficulties may be reduced by choosing the tillage alternative that is best suited for each particular crop field. In most cases, no-till will provide the highest benefits, but also be the most difficult to implement. Conservation tillage is a more flexible practice which results in the same advantages and disadvantages as no-till but to a lesser extent.

The following difficulties and benefits may be experienced when applying a no-till system instead of conventional tillage practices:

Advantages

- Soil erosion reduced.
- Energy savings by reducing labor, machine and fuel requirements.
- Decreased production costs.
- Fewer passes over field reduces compaction by heavy equipment and results in energy savings.
- Reduces surface crushing and sealing from raindrop impact if residue cover is adequate.
- Increased infiltration, if adequate storage is available in untilled field and residues. Decreases are possible if soil compaction occurs.
- Improved moisture conservation.

Disadvantages

- Increased nutrient and pesticide applications; may result in increased chemical movement.
- Decreased yields, though some farmers have experienced an increase in yields.
- Not suited to all croplands; dependent on soil and climate.
- Increased emphasis on management skills and need for technical assistance.
- Delays soil warming and drying.
- Poor germination may occur if difficulties in seed placement or poor soil conditions result from surface residues.
- Surface residues make seed nutrient and pesticide placement difficult.

The cost of implementing a conservation tillage system can be described in cost per acre, net returns, yield or cost per unit soil saved. Even when comparing system or net returns, significant factors such as environmental impact, soil loss, and long-term fertility are not included in the dollar value figure.

The cost of implementing conservation tillage varies widely. The success of conservation tillage as an economically viable alternative cannot be determined on a regional or even areawide basis. The cost of these practices will be dependent in part on the managerial practices, environmental conditions and implementation methods and will be different for each farm.

The following cost information (Crosson, 1981) was collected from a variety of sources. They were not provided to give the actual cost of applying an alternative tillage methods, but to demonstrate the general relationships between cost components and tillage practices. The table demonstrates a few of the variable component costs between conventional and conservation tillage. Pesticide costs increase for conservation tillage, particularly no-till systems where weed and insect control are difficult. Other costs that increase are seed and fertilizer costs since surface residues and planting difficulties require optimized placement, reduce germination rates and reduce nutrient availability. Costs which decrease by using conservation tillage include machinery, fuel and labor because the fewer the trips over the fields the higher the savings. With today's high fuel and machinery costs this savings results in a significant drop in cost.

	Cost Per Acre			
	Corn Conventional Tillage	Corn Conservation Tillage	Wheat Conventional Tillage	Wheat Conservation Tillage
Pesticides	$ 8.72	$ 11.63	$ 1.21	$ 1.61
Fuel	9.02	7.02	5.57	3.57
Machinery	36.32	31.32	25.30	20.30
Labor	13.24	6.62	9.25	4.63
Total Costs	$165.00	$154.00	$79.00	$68.00

Studies of the Western Lake Erie Basin determined net returns were highest for minimum tillage while chisel plow and no-till were similar or slightly higher than conventional tillage systems (Hemmer and Forster, 1978). The following table demonstrates the cost breakdown for sample farms in the Western Lake Erie Basin. It demonstrates how pesticide and fertilizer costs increase with conservation methods but how savings on other cost factors result in a decrease of total variable cost. Decreased cultivation costs may help improve net profits even if the yields decrease slightly.

	Cost Per Acre*			
	Tillage	Herbicide	Fertilizer	Total Variable Cost
Conventional tillage	$19.13	$14.17	$55.58	$172.12
Chisel plow tillage	14.79	14.41	52.69	165.01
Minimum tillage	11.00	14.38	64.42	171.69
No tillage	--	25.08	59.82	169.12

*Land costs excluded.

The Honey Creek Watershed Project found the cost of retaining soil using conservation tillage to be $2 to $9 per ton (U.S. EPA, 1980). The following table demonstrates how variable the results of applying conservation tillage can be within the Honey Creek Watershed:

	Cost Per Acre		
	Conventional Tillage	Conservation Tillage	No-Till
Number of plots	3	12	18
Average production costs	$192	$180	$198
Range	127-228	124-228	124-245
Average crop values	$227	$287	$271
Range	252-307	155-381	166-325
Average net return	$85	$107	$73
Range	42-125	-13-179	-36-181

Changing over to an alternative tillage method may require new equipment or large initial expenditures. Farmers may be reluctant to try alternative tillage methods because of the additional costs, risks of lower crop yields or the need for additional information. To encourage the use of alternative conservation tillage various agencies offer educational, financial or technical assistance.

Profit margins may influence a farmer´s outlook on a tillage system. To maintain net profits farmers may be more concerned with short-term rather than long-term benefits, and are more likely to adopt principles that increase profits than those which protect the environment. This may be true even when protecting the environment is a direct benefit to the cropland by retaining its soil fertility.

Farmer resistance to the use of conservation tillage is based on concerns about the risks of decreased profits, expenditures required to learn about the system, new or adapted equipment, and unknown results.

In an attempt to encourage conservation tillage, federal, state and local agencies have developed several programs. The purpose of these programs is to promote initial applications and to provide assistance to maximize the benefits of using conservation tillage.

Various agencies on the federal, state and local level are all oriented towards encouraging conservation practices. County Extension Services and Soil and Water Conservation Districts, the USDA´s Agriculture Stabilization and Conservation Service (ASCS) and Soil Conservation Service (SCS), and the Environmental Protection Agency (EPA) are all actively involved in promoting the use of alternative tillage practices.

Education-information programs are aimed at promoting acceptance, demonstrating the benefits to the farmer and providing information on how to best apply a specific tillage method. Research, monitoring and evaluation are being done by various agencies to determine the best use of tillage methods for increased crop yields, reduced costs and increased pollution control. Technical assistance provides information on the best management practices for a given cropland and tillage practice. It also provides assistance with adapting and operating equipment. Out of all the cropland conservation methods, conservation tillage requires the least technical assistance.

Financial assistance can be implemented in several different manners. Some counties have provided free planting to those willing to try conservation tillage or arranged for low rental rates on tillage equipment. Cost sharing has been available to farmers though low budgets have kept this method from making a big impact in the past. Federally financed incentive payments are available for farmers who leave at least 25 percent of the soil surface covered. In Minnesota payments of $10 per acre for conservation tillage and $14 per acre for no-till is available on a maximum of 80 acres for up to three years (Brandt, 1983).

Financial, technical and educational assistance are aimed at two things. The first is to convince farmers to try new tillage techniques. Education programs, financial incentives, literature and local promotions encourage farmers to try conservation measures. A Wisconsin study surveyed farmers and found the most important reason for convincing farmers to try conservation tillage was the "neighbors" (Pollard et al., 1979).

The second orientation of assistance is to promote the best use of tillage methods. Farmers may try conservation tillage but unless the method provides results and is economically beneficial they will not remain with this tillage method. Technical and educational programs promote the best use of conservation tillage and combat any disadvantages that might arise from using this alternative tillage method. Other assistance in the form of research, monitoring and evaluation is continued to improve conservation tillage practices.

CONTOUR PLOWING

DESCRIPTION AND PURPOSE

Contour plowing is the application of all cultivation operations parallel to the contours of the land. Contouring produces low ridges that interfere with overland flow by diverting it laterally and increasing surface storage. The purpose of contouring is to reduce erosion and increase infiltration. Reduced erosion reduces some cropland soil losses and surface water sediment loadings.

TARGET APPLICATION

The target pollutants of contouring are sediment and nutrients. These pollutants originate from the loss of soil during crop cultivation.

Contouring is not applicable in every situation. Contouring should only be applied when topography and drainage are compatible with contouring principles. Contouring is not needed on level croplands and it is ineffective on steep or long slopes. The cropland topography may limit applications because of difficulties of following complex contours with multiple-row equipment. Contouring should only be applied on soils with good drainage since poor drainage may result in excess water overflowing contour ridges causing heavy erosion.

Contouring applications are limited by physical compatibility requirements. These limitations can be eliminated by combining contouring with alternative cultivation practices such as contour strip cropping or conservation tillage. Combining contouring with structurally supporting practices such as terracing or diversions allows the use of contouring in more situations.

EFFECTIVENESS

The effectiveness of contouring at reducing surface water pollution is dependent on field characteristics and precipitation. Certain soils and slopes are not compatible with contouring practices. Flat, extremely steep or lengthy slopes will not benefit much from contouring applications. Heavy rainfall may also result in reduced effectiveness at preventing erosion. The following data were determined for contouring on a two to 12 percent slope (Oberts, 1981):

	Percent Reduction
Runoff	10-70
Erosion	40-85
Nutrients	25

The following table was developed using land and climate data from three different states (Haith and Loehr, 1979). The table shows the general relationship between runoff, percolation and sediment reductions due to contouring instead of straight row cropping. Also listed are dissolved and adsorbed nutrient reductions. Contouring is highly effective at retaining solids (sediment and nutrients) because it controls erosion. It is much less effective at reducing runoff, therefore, dissolved pollutants continue to pollute surface waters.

Annual Runoff, Sediment and Nutrient Losses of Contouring
In Percent Reduction from Conventional Practices

	Runoff	Increased Percolation	Sediment	Dissolved N	Dissolved P	Solid-Phase N	Solid-Phase P
New York	40	+10	65	50	45	65	65
Iowa	15	+15	55	25	20	55	55
Georgia	30	+10	60	35	30	60	60

PLANNING CONSIDERATIONS

Contouring is best used under compatible conditions or in combination with other conservation practices. Contouring should be planned and used in a manner that minimizes ridge overflows. When runoff breaks over the row, it overflows lower contour ridges resulting in failure of the contours.

To provide the best use of contouring, soil, climate and topographical factors should be considered. Because of physical limitations, contour farming is frequently recommended as a portion of an overall conservation plan for use in combination with additioal control measures. For instance, contour strip cropping or contour terracing combine techniques for a more effective conservation practice.

Information and technical assistance are available from several different agencies such as the USDA-Soil Conservation Service and County Soil and Water Conservation Disticts on the implementation of contour farming. Contouring requires little technical assistance compared to more structural practices.

DESIGN CONSIDERATIONS

The ease with which contouring is developed and used is dependent on the topography. Technical assistance may be needed to develop the contour intervals and placement. Following contours and possible row convergence leads to operational inconvenience which results in time and cost increases. Under some topographical conditions large farm equipment can become difficult to use. A different disadvantage involves the integrity of the contour ridges. Little can be done about weathering which wears down ridges except to apply additional methods such as diversions.

Contouring is considered to be a low cost soil conservation alternative. Its use results in a slightly higher total variable cost. Compared to continous straight-row conventionally tilled corn, contouring increased equipment and labor costs by about 10 percent (Haith and Loehr, 1979). Contouring can frequently be implemented with little change in farm income unless additional methods are jointly applied.

TERRACING

DESCRIPTION AND PURPOSE

Terracing is a structural method of controlling runoff on sloping croplands. Slopes are divided into step like segments with an embankment or channel combination. Embankments are constructed to create level or graded areas for crops. While diversion terraces are designed as channels across the slope which direct runoff away from critically eroding areas or terrace systems.

The terrace gradient, cross-section, alignment and outlet can all be designed to provide the best protection. The purpose of terracing is to reduce erosion and soil loss by enhancing infiltration or dissipating runoff water energy. Infiltration increases when level ground provides surface storage and embankments delay runoff by directing it over longer pathways. Terraces reduce the slope length and gradient which results in lower runoff velocities and soil losses.

TARGET APPLICATIONS

The target pollutants that terracing controls are sediments and adsorbed nutrients and pesticides. Terraces reduce soil erosion and solids transportation which usually results in improved water quality.

Terraces are applied on sloping agricultural lands, particularly croplands that have heavy erosion. Terraces are used on moderate or long slopes to reduce the gradient, and are used when crop cultivation on these slopes causes erosive damage. Terraces are also useful as a method of altering steeper sloping areas or irregular topography to a shape more suitable to intensive cropping practices. Terraces are generally not used on very steep slopes or shallow subsoils because the construction disturbance counters the benefits that are received from terracing.

Terraces can be adapted to most sloping conditions. Because terraces are quite expensive, limitations on terrace applications are likely to be financial rather than physical. A cost-effective analysis should be done to determine if a different conservation method would be better. Analysis on whether terraces are the most cost-effective solution for a specific field should consider topsoil type and depth, soil erodibility, slope, type of terrace and level of management.

EFFECTIVENESS

The effect of terracing on water quality will vary with the crop, climate, field characteristic or terracing design. Because of the wide variety of variables, each individual field may have different water quality effects when terracing is applied.

The effectiveness of terraces at keeping pollutants from surface waters is dependent on the pollutants´ properties. Terracing is very effective at reducing erosion and sediment transport, therefore, sediment and adsorbed nutrients or pesticides are kept from water courses. However, terraces have little effect on overland flow, except impoundment terraces; and, therefore, they are relatively ineffective at reducing soluble nutrients and pesticides from polluting surface waters.

Effectiveness figures may change for a specific terrace design. The following table illustrates the possible effects terracing has on runoff water.

Pollutant	Percent Reduction
TSS	50-90
Nutrients	35
Pesticides	50

Twenty-five year simulations were done by Haith and Loehr (1979) to project the following figures for mean annual percent reductions as compared to conventional tillage:

	Runoff	Percolation	Sediment	Dissolved Nutrient	Solid-Phase Nutrient
New York	60	+15	95	+70 to -60	95
Iowa	30	+5	95	30	95
Georgia	40	+15	95	+40 to -50	95

PLANNING CONSIDERATIONS

Terraces can be best used by altering the alignment, gradient, outlet or cross-section according to site characteristics. The alignment can be parallel or non-parallel to the field slope. The gradient may be planned as level or uniformly graded. Level terraces are used when moisture conservation is desirable while graded terraces provide controlled disposal of excess runoff. Graded terraces are not effective at reducing runoff volumes but they do control erosion and sediment transportation.

Terrace outlets consist of an impoundment area, with vegetated waterways or reinforced outlets. Impoundment terraces are constructed to infiltrate surface runoff by increasing detention storage. Impoundment terraces are best used on permeable soils or dry areas where moisture conservation will improve crop yields. Increased infiltration may cause higher soluble nitrogen levels in the groundwater under some soil and climate conditions. The outlet can be designed to detain water by releasing it at a slow rate but should not be underdesigned since standing water may damage crops. Outlets can be designed to in sediment removal from terrace runoff. Large amounts of sediment are deposited in channels or drains. Using a tile outlet may prevent a large percentage of eroded soil from leaving the terrace. Difficulties with accumulated sediment in channels may require additional maintenance.

A terrace cross-section design and placement can be altered according to site specifications. The choice of bench, steep back slope, base width, channel or embankment should be made to best fit site characteristics and cultivation requirements. Terrace placement involves the horizontal spacing of terraces. The terrace interval is dependent on the slope steepness, soil, precipitation and crop management. Standard formulas are available to indicate recommended terrace intervals.

To qualify for cost-sharing assistance through the ASCS, design requirements must be followed. Unfortunately, in some cases these intervals are not the most cost-effective method of controlling slope erosion. Reducing the terrace interval slightly increases the effectiveness but cost increases at a faster rate than erosion reduction. One simulation study (Haith and Loehr, 1979) determined that a single terrace on the lower edge of the field, which used sediment basin principles was the most cost-effective alternative for reducing sediment delivery to surface waters even though it did not effectively reduce erosion.

In some cases terraces are best used in combination with other conservation practices. For instance, contour terracing is frequently applied to increase control of runoff and erosion. The best use of combined practices is dependent on site characteristics. In some cases increased management requirements make contour terracing impractical. Other alternatives--chisel plowing, strip cropping and no-till--can be combined with terracing for additional erosion reduction.

DESIGN CONSIDERATIONS

The initial construction cost of installing a terrace system makes it the most expensive agricultural soil conservation practice available, with the actual cost varying by site characteristics and terrace design. Construction costs generally depend on two variables, field slope and terrace type. Lower slope and gradient terraces are least costly while tile outlet storage terraces and steep slopes increase the terrace construction cost. Estimated construction costs in Illinois for 1978 on slopes ranging from 1 to 15 percent were \$60-\$950 per acre (Mitchell et al., 1980).

During construction, practices should be used to minimize soil disturbances and control sediments. Improper construction practices can result in high erosion rates. Construction disturbs the topsoil layer which may result in initial decreases in crop yield. However, unless the topsoil is shallow, yields should increase to nonterrace levels or better.

Increases in crop yields help compensate for increased production costs. Yields may increase because of improved moisture utilization or a design which allows more intensive management practices. The actual yield will depend on physical land characteristics, climate and management skills. One Wisconsin study found terraced corn yields increased 126 percent after three years while a five-year trial showed terraced hay yields increased 11 percent (Haith and Loehr, 1979).

Depending on the cropland characteristics, a possible increase in equipment and labor costs may occur. Field efficiency may decrease if cultivation space is used for the terrace structure. Terraces will require additional maintenance to correct damage from weathering though elimination of gullies that occur with conventional plantings or moderate slopes might result in an overall reduction in maintenance costs.

A study on the effects of terracing from the landowner's standpoint looked at the costs and benefits of installing terracing (Haith and Loehr, 1979). They found that the only time terracing increased farm income occurred with a gradient terrace system applied on highly erodible soils, unfavorable subsoils and high levels of management. In most cases terracing results in a loss of farm income. However, the decision to use terracing relies on additional benefits such as prevention of environmental damage (cropland soil loss, water pollution) which is not reflected in the loss of farm income.

The application of terracing is frequently dependent on government programs which reduce the installation cost. Terracing requires considerable technical assistance and financial aid to be considered in a competitive range with other conservation practices. Terracing requires the highest level of technical assistance compared to alternative soil conservation practices.

Cost-sharing for structures is usually received as a fixed percentage of initial installation costs with a maximum annual payment. To qualify for the ASCS cost-sharing program, terraces must meet certain standards set by ASCS and SCS. The goal of a cost-sharing program is to help farmers reduce nonpoint source pollution from agricultural land. In some cases where the best terrace alternative does not follow the conventional design and, therefore, would not be eligible for financial assistance, cost-sharing may encourage the use of a less cost-effective terrace system.

STRIP CROPPING

DESCRIPTION AND PURPOSE

Strip cropping is the use of strips of close growing or sod crops between tilled row crops. Strip cropping creates a barrier that checks runoff flows resulting in reduced erosion. Sod strips are planted perpendicular to the erosive force, runoff or wind. The purpose of strip cropping is to provide a buffer area between strips of row crops to prevent cropland soil loss.

TARGET APPLICATIONS

The target pollutants that strip cropping controls are sediment and associated nutrients. Strip cropping reduces erosion and transportation of these pollutants to surface waters by stabilizing buffer areas to dissipate runoff energy and by providing sediment filter areas.

Strip cropping is applied when soil losses occur with tilled row crops. A sloping field may result in increased erosion from runoff. Strip cropping is effective on low to moderate slope steepness. Strip crops perpendicular to prevailing winds provide surface cover that prevents wind erosion.

EFFECTIVENESS

Strip cropping can be an extremely effective method of controlling erosion and keeping soils on croplands and out of surface waters. Strip cropping can reduce soil loss by up to 85 percent (IJC, 1977)) when combined with contouring or rotation. The actual effectiveness will depend on the strip design (strip width and plant type) and the field characteristics (slope and soil).

PLANNING CONSIDERATIONS

Strip cropping is frequently applied in combination with crop rotation and/or contouring. Contour strip cropping results in row crop and sod crop strips parallel to the slope contour. Strip cropping is compatible with crop rotation practices and almost always implies the use of rotations.

Strip cropping has a minimal effect on runoff volume but improves surface water quality with reduced sediment transport by slowing water velocity and increasing filtration. Only when contouring is used to create additional surface storage depressions does infiltration increase resulting in reduced runoff volumes.

For the best use of strip cropping, field characteristics, cropping practices and crops should be considered to develop the best combination. Strip cropping has a strip of meadow crops planted between a strip of row crops. To provide the most effective use of strip cropping compatible crops should be chosen. Hay is the most commonly applied strip crop even though sod is more effective than small grains. Unless small grains can be utilized, strip cropping a less attractive alternative, since sod-based strips require land that might otherwise be used by cash crops.

DESIGN CONSIDERATIONS

The cost of strip cropping results from the potential loss in profit, possible increase in cultivation costs and inconvenience in cultivation. Information on strip cropping indicates that crop yield often increases, although decreases are possible. Strip cropping yields include a percentage of sod or small grain crops. Even when these can be used, lower cash income can result from reduced cash crop productions. Changes in variable costs may increase cultivation expenditures, depending on the field characteristics and management skills. Decreases in nutrient or pesticide applications and increases in equipment and labor costs may effect the total cultivation cost. Strip cropping may be difficult to implement if field topography and strip width are not compatible with the available farming equipment.

Government agencies provide technical and financial assistance to encourage the use of conservation practices by farmers. Strip cropping requires low levels of technical assistance even when combined with contouring. Cost-sharing may be available in the form of an incentive payment for every acre with strip cropping. Payment rates vary and are subject to change. For present rates contact the local SCS or ASCS agencies.

CROP ROTATION

DESCRIPTION AND PURPOSE

Crop rotation requires planting alternating crops according to a rotational schedule. This method plants row, small grain and sod crop in succession as an alternative to a single continous crop. The purpose of crop rotation is to control erosion and the resulting soil loss. Crop rotations can also be developed that provide soil conditioning, nitrogen fertilization and pest control.

TARGET APPLICATIONS

The target pollutants controlled by crop rotation are sediment, nutrients and pesticides. Crop rotation is a flexible planting alternative that can be planned to fit most farming operations. The rotational schedule and crop choice can be planned to provide the maximum soil protection without causing financial or cultivation problems. Crop rotation can be applied when problems with erosion, runoff, soil fertility or pests result from continuous cropping practices.

EFFECTIVENESS

The effectiveness of crop rotations depends on the rotational schedule and on the choice of plant species. Sod crops create almost no contamination of surface waters and reduce runoff volumes while row crops cause the largest amounts of soil loss, some of which is transported to surface waters. Management practices can also be altered to provide a more effective soil containment practice. Using the residue of previous crops reduces soil movement to waterways. For example, planting small grains in disked corn residues or plowing under sod before planting row crops.

Reductions in water pollution are uneven throughout the rotational cycle, but a high overall effectiveness is common. The highest reduction in sediment pollution occurs during sod rotations. Compared to conventional row crops, sediment loads are also reduced during row crop rotations that directly follow sod crops. The average overall reduction of most pollutants when using crop rotations is between 20-60 percent (Oberts, 1981).

PLANNING CONSIDERATIONS

Crop rotation practices are best used by developing a planting schedule according to field requirements, plant management principles and farmers' advantage. Crop rotation should be planned to minimize erosion and runoff reductions. The schedule may be organized to control some diseases and pests. Pesticide applications may be reduced by eliminating host plants, disturbing insect development cycles and alternating to crops where pesticide applications are more effective or mechanical controls are possible. Rotating crops provides better alternatives for nutrient application and incorporation of sod crops or organic crop residues can provide soil conditioning.

Crops should be arranged in the most effective combination and order. Numerous combinations of row, small grain and sod crops could be used for crop rotations. Several of the commonly rotated crops include corn, hay, wheat and clover. Crops should be scheduled to reap the benefits provided by previous crops, such as crop residues, soil conditioning or pest elimination. Commonly used schedules include one to two years of corn after following a year of incorporated or chemically killed sod. Another combination is a small grain seeded in disked corn residues. Some combinations are not appropriate if they actually produce higher erosion rates such as corn following soybeans.

DESIGN CONSIDERATIONS

The cost of applying crop rotation is dependent mostly on crop selection, tillage practice, soil type and mangement skill. Costs can be calculated in terms of variable costs, gross income and net income.

Variable costs generally decrease by switching from continuous crops to rotation crops. Nutrient and pesticide costs decrease, labor costs may vary either way and equipment costs will remain the same or increase. The only time variable costs would be expected to increase is if a farmer owned specialized equipment and had to purchase additional machinery to meet new cultivation needs.

Total yields might increase due to better soil conditions but higher yields rarely compensate for the loss of cash crop acreage. Unless the farmer can use noncash crops or a market exists for crops such as hay, the reduction in net income may discourage use of crop rotations to control nonpoint source pollution from croplands.

OPTIMIZE FIELD CONDITIONS

DESCRIPTION AND PURPOSE

Optimizing field conditions involves the use of several diverse principles including optimized cropping practices and soil surface coverage. The purpose of controlling field conditions is to reduce the availability of pollutants by reducing soil exposure to transportation modes. The methods tend to center around better utilization of vegetation to protect soil surfaces. Typical procedures include improved cropping, row spacing, placement and timing; use of mulch and crop residues; critical area seeding; cover crops and wind breaks; and buffer strips or filter strips.

TARGET APPLICATIONS

The major target pollutant controlled by optimized field conditions is sediment. Field conditions are altered to prevent soil losses due to erosion. Secondary pollutants that may be controlled with this MP include nutrients and pesticides, particularly those in solid-phase which are associated with sediment.

The target applications of optimized field conditions are any situation where the soil surface is conducive to erosion. The highest erosion levels occur before crop establishment or on critically eroding areas. The times to consider altering field conditions are when soil surfaces are exposed or when critical areas such as steep slopes occur immediately adjacent to surface waters.

EFFECTIVENESS

Optimizing field conditions is most effective on sediments and solid-phase nutrients. These methods generally have little effect on soluble chemicals. The following table lists a few of the effects on surface waters by several different practices (Oberts, 1981). Most field stabilization methods are difficult to quantify so little data are available to show the relationship between the MP and water quality.

Stabilization Practices	Percent TSS Reduction	Percent N & P Reduction
Residue management, sod and mulching	40-75	0-75
Buffer, filter strips	0-50	0-50
Field windbreak	0-40	---

PLANNING CONSIDERATIONS

Many actions can be taken to optimize field conditions. The best use of this MP can be determined by considering the specific area characteristics and which practice is best suited to control the pollution problem. Optimized cropping practices can be applied to reduce soil losses. Timing of planting and harvesting to reduce soil exposure during periods of heavy precipitation, placement of crops parallel to slopes and changing row spacing to provide dense surface coverage are a few of the available alterations of cropping practices. A disadvantage of using methods such as altered timing is increased risk of lower yields due to variable weather conditions.

Vegetative buffer strips can be used as a border around agriculture fields or surface waters. Buffer strips around agricultural fields provide edge-of-the-field filtration and some runoff reductions. Broader strips provide erosion control at the edge of the field, but not in the field itself. They are recommended for use on critical areas, around surface waters. Buffer strips between croplands and streams or lakes protect surface water quality by slowing down overland flow and filtering field runoff. Buffer strips also protect streambanks that might otherwise be damaged by cultivating land up to the banks' edge. The effectiveness of this method is highly dependent on the vegetation type, buffer strip width and runoff volume.

Practices that provide field coverage when crops are not being grown can be used to prevent soil erosion. Cover crops can be planted after harvesting to provide coverage during winter and early spring months. Cover crops can be plowed under before planting which may provide soil conditioning and nutrients though some cover crops may actually remove nutrients or cause decreased yields. Mulches or previous crop residues applied in the fall can prevent erosion before spring crop establishment. For details on the use of mulches, see the urban-erosion control-mulch section.

Alternatives in field preparation used to reduce soil loss due to wind erosion include surface roughening and windbreaks. Rough surfaces with large soil clods, protecting mulch or residues are less likely to be moved by high winds. Windbreaks frequently involve rows of vegetation with their use and effectiveness depending mostly on the species.

DESIGN CONSIDERATIONS

The cost of optimizing field characteristics will vary with the site, practice and extent of application. Some of the practices may actually result in higher crop yields. These practices include optimized cropping, spacing, timing and placement, improved soil fertility, mulching, residues and incorporated cover crops. The cost of practices such as critical area seeding, buffer strips and vegetative windbreaks can be calculated in terms of both establishment costs and land costs. Land costs represent the value of the property taken out of crop production for the purpose of erosion control.

Optimizing field conditions is relatively easy to develop and use. It requires identifying problem areas that need additional erosion controls, determining the best solution and installing controls or altering present practices. In most cases, none of the practices suggested require additional equipment or require large expenditures in time or money for effective use.

LIVESTOCK MANAGEMENT

LIVESTOCK EXCLUSION

DESCRIPTION AND PURPOSE

Livestock having direct access to a waterway may have harmful effects on the water quality. Streambank erosion increases if livestock are allowed to trample the banks. Animals walking through the water may disturb bottom sediments causing them to resuspend or livestock may defecate directly into the waterway.

The purpose of livestock exclusion is to keep animals away from streams where direct deposits of fecal matter and increased sedimentation can degrade water quality. Streambank fencing and crossovers may be installed to prevent livestock access to a waterway. Where the water course is necessary for drinking water, controlled access (gravel or concrete ramps) may be designed or water may be directed offstream to an alternative watering site.

TARGET APPLICATION

The target pollutants are suspended solids from increased erosion of streambanks or stirring up of bottom sediments and nutrients from livestock defecation. Secondary pollutants that occur from the direct deposit of animal manure in waterways include: solids, oxygen-demanding substances, bacteria and viruses.

Livestock exclusion should be practiced when animals have direct access to a watercourse. When feasible, animals should be fenced away from waterways. Watercourses needed for watering should apply controlled access to limit livestock intrusion to one point. A controlled site should have bank stabilization measures applied to minimize erosion.

EFFECTIVENESS

Livestock exclusion eliminates direct discharge of wastes into the receiving water and minimizes streambank erosion. Total exclusion can provide up to 100 percent fecal matter reduction and 50 percent streambank erosion control for streams where animal access now exists (Oberts, 1982). Controlled access will provide lower amounts of pollutant reduction, though the method is still considered highly effective.

PLANNING CONSIDERATIONS

The application of livestock exclusion eliminates one source of pollution. The advantages include reduction of livestock wastes in the waterway and stabilization of streambanks, which benefit the property owner as well as downstream water users. Other indirect benefits occur; one documented example showed that after a dairy farmer installed a culvert to keep his cows out of a stream on the way to pasture, the cows' milk was found to contain less sediment (U.S. EPA, 1980).

DESIGN CONSIDERATIONS

The costs of livestock exclusion will vary with the type of installation. Fencing is expensive, while costs will increase with more structural methods such as access ramps and may be extremely high if exclusion from streams requires the development of alternative livestock watering sources. Exclusion methods may be financed in part through various cost-sharing programs. The following values are estimated capital costs for the construction of example exclusion methods (IJC, 1977):

Concrete or gravel ramps	$250 - $500 each
Fencing	$1.40 - $2.50 per linear yard

Operation and maintenance needs would be met by the property owner. O & M might include regular cleaning of accumulated manure in controlled access areas and repair of damage to fencing or exclusion structures. Livestock exclusions generally have very few O & M needs.

Livestock exclusion methods are easy to develop and use. Simple fencing methods have been widely used, are inexpensive and effective. More structural methods have increasingly higher development costs and development and use difficulties. Exclusion methods should be applied in accordance with the property owners needs as well as water quality needs.

FEEDLOT MANAGEMENT

DESCRIPTION AND PURPOSE

Feedlot management is the manipulation of site characteristics to control runoff and animal wastes. Feedlots contain dense populations of livestock which provide a concentrated source of pollutants. The purpose of feedlot management is to prevent the loading of surface water with animal wastes.

Feedlot management may involve altering drainage characteristics to reduce the transportation of nutrients from the lot. Diversion structures are installed to prevent clean water from entering the site while a collection system is installed to keep runoff from leaving the site. Settling basins and retention ponds may be constructed to store the accumulated polluted runoff until it can be discharged to a waste disposal system. Other management practices used to control feedlot water pollution include maintaining buffer strips and reduced animal-to-land ratios.

TARGET APPLICATIONS

The target pollutants include nutrients (phosphorus, nitrogen), oxygen-demanding materials and bacteria.

Feedlot management should be applied to all major livestock operations. High levels of management may be needed when the feedlot is sited in a critical area. Critical areas are designated by the following criteria: distance to a stream, feedlot slope, number of animal units, or any area with a high potential for severe pollution problems.

When feedlots are located away from surface waterways, overland flow may remove some nutrients if the land contains stable vegetation. Feedlots located close to streambanks lack the natural buffer zone resulting in higher percentages of pollutants transported to the waterway. Therefore, feedlots located close to streams will require more intense management practices.

Feedlots with steep slopes may rapidly drain animal wastes as well as runoff directly to a waterway. Feedlots are frequently constructed to use natural drainage to keep the area dry. Unfortunately, drainage frequently flows directly to surface waters. Controls can be implemented by changing the natural drainage patterns with regrading or diversions. Large numbers of animal units will create larger quantities of pollutants. It is important to apply correct animal-to-land ratios to avoid overcrowding that may result in increased water quality and lot degradation.

The application of structural runoff control methods may not be economically feasible for small scale livestock operations. When viewing the addition of runoff controls to feedlots as added production costs, studies indicate that location and feedlot size will determine the actual price per head production cost increase (Miner et al., 1979). The following table illustrates the increase in production costs in dollars per head with varying feedlot size and location (Miner et al., 1979). Midwest feedlots consist mostly of small livestock operations, where high runoff control costs prevent the application of structural methods without public aid, while increased production costs for large scale operations are insignificant. The following cost increases assume an animal turnover rate of three times annually. In cases of smaller feedlots having only one group of animals, the costs shown will triple. The costs include runoff collection, detention and water disposal systems.

Feedlot Location	Feedlot Size (acres) 1.0	10	100
Ames, Ia	1.52	0.55	0.43
Bozeman, Mt	1.39	0.43	0.31
Corvallis, Or	1.78	0.77	0.64
Experiment, Ga	1.64	0.64	0.56
Lubbock, Tx	1.43	0.47	0.35
Pendleton, Or	1.16	0.23	0.12

- All systems are the least cost system for each location: pumping rate equals 0.05 times 25 year-24 hour storm, year round waste disposal, hand moved irrigation system and nutrient utilization disposal policy.

- Assumes a feedlot capacity of 200 head per acre, three times yearly animal turnover and 100 percent use of capacity. 1977 cost data used for analysis.

EFFECTIVENESS

Runoff management is considered to be a highly effective method of protecting water quality. Completely eliminating discharge to the waterway would provide 100 percent reduction of feedlot pollutants at that point. The actual effectiveness of the total feedlot management depends on the waste disposal system.

A feedlot management system which controls animal wastes on-site for future incorporation into unfrozen fields would reduce pollutant delivery to water systems. Some sites would have reductions around 50 percent for nitrogen and phosphorus and 50 percent for COD. Higher overall reductions may be achieved with more intense treatment methods (Oberts, 1982).

PLANNING CONSIDERATIONS

To provide the best management of feedlots the facility requires proper design. Feedlots should be designed to manage runoff and animal wastes without polluting surrounding surface waters. Collection, storage and disposal systems should be chosen according to site, water quality and livestock operation requirements.

Management system components that can be varied include drainage system capacity, storage volume and waste disposal (rate, frequency). The factors that should be considered during the design are climatic conditions (design storm, precipitation), feedlot size (area, animal units), disposal and drainage areas (soil type, runoff rate).

The best method of containing feedlot manure is to control feedlot runoff. To reduce the runoff quantity that must be controlled, runoff from surrounding areas should be diverted away from the feedlot site. Preventing clean water from entering the site reduces the amount of waste water that must be disposed of. Besides improving water quality, diverting runoff away from the feedlot benefits the feedlot operator by providing a drier barnyard. A farmer in Delaware County, New York, found barnyard grading and installing a tile line and outlets to catch runoff helped reduce hoof disease in his herd by creating a drier barnyard (U.S. EPA, 1980). Similar livestock health benefits may occur for feedlot operations.

The design of the feedlot area can be improved to control runoff. On-site control of feedlot pollutants requires the use of a collection system. Runoff can be collected by installing drainage ditches or diversions. Grading can be applied to direct runoff to a desired point by sloping drainage. Buffer areas may be used to provide areas that will filter runoff.

Collected runoff can be directed to a storage facility. The type of storage will generally depend on the waste disposal system. In some cases, manure is stored dry in on-site stacks or packs. Dry storage may be less expensive but is not adequate for all situations. Alternatively manure mixed with feedlot runoff is stored as a liquid in slurry storage tanks or retention ponds.

The final process is waste disposal, which could include irrigation or treatment systems. For more information see the following section, Waste Disposal Systems.

Figure 23 was derived by a computer model for a 100-acre feedlot in Pendleton, Oregon, using runoff data from 1914-1971 (Maier et al., 1979). The analyzed runoff control system consists of a storage basin, hand moved irrigation system and year-round pumping for nutrient utilization waste disposal. Comparisons weremade by reducing storage volume and daily pumping rate, which created higher percentages of uncontrolled feedlot runoff. EPA runoff guidelines were set as 100 percent of the runoff contained. The computer similation showed that only 60 percent of the costs would contain 90 percent of the runoff volume. The figure illustrates how reducing runoff controls by small quantities can provide large cost savings. This cost savings is only practical where the receiving water is capable of dissipating the additional runoff load.

Regulatory requirements for the use of management techniques to control feedlot pollution stems from the National Pollution Discharge Elimination System (NPDES). The U.S. EPA has set up effluent guidelines which permit discharge from feedlots only during an "unusual rainfall" event. The 1983 definition of an unusual rainfall is a 25 year-24 hour storm (Miner et al., 1979). These guidelines are recommended but compliance is optional for smaller feedlots.

This method of controlling feedlot discharge by setting a performance standard for a single storm event may not be effective. Studies have indicated that design capacities are controlled more by chronic precipitation conditions rather than a single large storm (Miner et al., 1979). States are expected to develop further guidelines for livestock operators to insure an environmentally sound facility. State and local programs are encouraged to promote compliance with suggested guidelines.

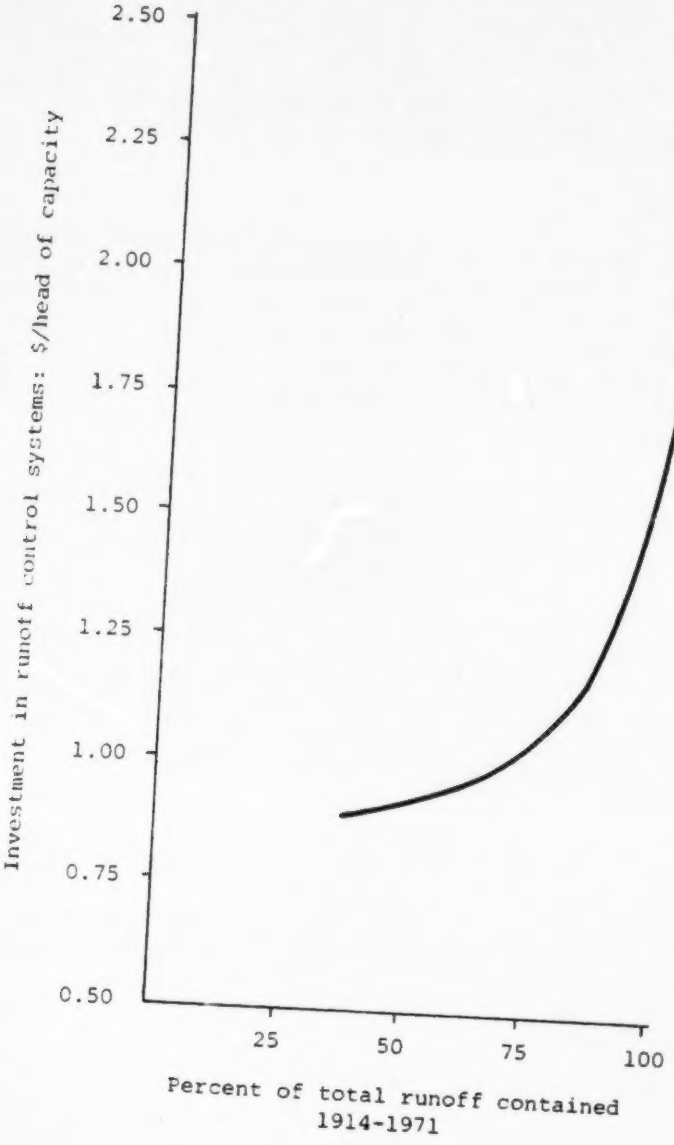

Figure 23. Simulated Cost and Performance of a Feedlot Runoff Control System. Source: Miner et al., 1979.

The Minnesota Pollution Control Agency (MPCA) rules for controlling pollution from animal feedlots are referenced as 6 MCAR 4.8051. These rules comply with State of Minnesota laws on pollution control regarding storage, transportation and utilization of animal manure. MPCA regulates these operations by requiring either a certificate of compliance or an MPCA permit for all animal feedlots. A feedlot is defined as having 10 or more animal units.

The certificate of compliance is a letter stating that the feedlot meets agency requirements. This certificate will not be issued if the feedlot is determined to be a potential pollution hazard, in which case a permit must be obtained to operate the feedlot. A permit is a document issued by the MPCA stating requirements, conditions and compliance schedules relating to the discharge of animal manure pollutants. To receive a permit, feedlot management and design plans must be adequate to prevent hazardous pollution discharge.

DESIGN CONSIDERATIONS

Initial costs might include earth excavations (clean water diversions, retention ponds, drainage ditches), structural storage, vegetative stabilization of earthen areas, land costs, engineering and surveying costs. Generally, collection system costs are relatively low, while storage facility costs vary depending on land values and structural needs. The disposal system will usually be the most expensive part of managing feedlot wastes. For specific cost information see the Detention Basin and Diversion sections.

Since most systems are not mechanically operated, controlling runoff requires very few O & M expenditures other than labor. Most of the operating costs will be included in the disposal system. Feedlot management plans must be developed specifically for each feedlot operation. Small operations may not be able to cope with the cost of runoff control measures. In most cases, state or federal cost-share programs are available to help defer part of the pollution control cost. In Minnesota both state and federal tax credits are available for taxpayers installing pollution control facilities. A 10 percent federal investment credit is available for certified pollution control facilities. Minnesota Statute Section 290.06 Subsection 9(a) (1979) allows a 10 percent credit on feedlot pollution control equipment (MPCA, 1981).

WASTE DISPOSAL SYSTEM

DESCRIPTION AND PURPOSE

Livestock operations can represent major contributions to agricultural water pollution. Waste disposal systems can mitigate this contribution by utilizing land or storage based treatment methods for disposal of collected livestock wastes.

The two types of land applications are nutrient utilization and waste deposition. Nutrient utilization is the application of wastes at rates beneficial to crop production. Wastes are frequently applied to croplands through irrigation systems. Livestock wastes are applied to cropland because of their value at providing nutrients and soil conditioning. Land used strictly for waste disposal can receive higher rates of waste deposition. Land used for waste deposition has no alternative uses, so the value of the land must be added into the cost of the waste disposal system. Wastes should not be spread on frozen ground or on steep slopes.

Storage treatment methods may be applied to livestock wastes to treat the effluent before discharging to a waterway. Detention facilities designed to remove pollutants include settling basins, treatment lagoons and natural wetlands. Wastes are generally subjected to both biological and physical treatment before discharge to the surface water.

The purpose of a waste disposal system is to deal with livestock wastes without discharging excess levels of pollution into surface waters. Some forms of land application have the additional purpose of conditioning and enriching the cropland soil.

TARGET APPLICATIONS

The target pollutants are all substances associated with animal manure. Pollutants from animal wastes include nutrients (phosphorus, nitrogen), organic materials (oxygen demand) and pathogenic bacteria and viruses.

Waste disposal systems are applied when animal manure is a potential pollution problem. The systems are used after a collection system has contained wastes. The waste system is usually developed in conjunction with a storage facility where wastes are stored until the appropriate time for disposal.

Animal manure has a high nutrient and organic content. Land applications for nutrient use are made when suitable land is available, and when nutrient benefits with water quality improvements outweigh the costs. For use as a nutrient supplement, the application rate must be low enough so that runoff does not occur. Crop nutrient requirements should correspond with runoff nutrient content. Salt and nutrient buildup should be monitored so as not to cause a problem. Wastes should not be applied to cash crops such as fresh fruits or vegetables when contamination may cause problems.

Land applications should be made when nutrient losses through runoff and erosion will be minimized. Application of waste will depend on the soil type, disposal method, climate (temperature, precipitation), crop and tillage practice. Limitations on when not to use land applications include, frozen ground, steep slopes, vicinity to surface drainage, potential for groundwater contamination, the potential for long-term soil damage from accumulating salts, or the potential for a health hazard.

Storage treatment methods can be used to dispose of livestock wastes. Treatment methods can only be used when they are effective enough to meet receiving water quality criteria. Settling basins will rarely provide adequate treatment for direct discharge. Usually settling basins are used as pretreatment to remove excess amounts of suspended solids that might otherwise interfere with other disposal procedures. Treatment lagoons are applied only when direct field application is not possible and storage treatment is the only alternative.

EFFECTIVENESS

The application of waste disposal systems for handling livestock wastes is highly effective. The actual effectiveness is dependent on the system used and application procedures followed. A total feedlot management system including on-site controls and incorporation of wastes into unfrozen fields was estimated to reduce pollutants at some sites up to 50 percent for COD and 50 percent for nitrogen and phosphorus (Oberts, 1982). Another study reports that an animal waste control system would reduce pollutants 50-75 percent (SEWRPC, 1981). A study conducted by the Internation Joint Commission (PLUARG) on the great lakes basin found implementation of animal waste control systems reduced animal waste phosphorus 27-36 percent (IJC, 1977). In this particular case that achieved a 9-13 percent total great lakes phosphorus reduction.

Treatment methods generally provide high levels of pollution removal. Settling ponds remove varying quantities of sediments and associated pollutants depending on the detention time and basin design. Treatment lagoons are used when direct field applications are not practical. The actual efficiency will vary by site depending on the quantity of algae and micro-organisms in the effluent. Removal efficiencies range from 20-90 percent for TSS, 27-90 percent for BOD_5 and 20-65 percent for phosphorus and nitrogen (IJC, 1977).

PLANNING CONSIDERATIONS

The waste disposal system should be chosen according to the needs of each specific site. The type of system should provide the desired improvement in water quality while remaining compatible with the owner's needs and land use. The waste input, storage volume and disposal output should be designed to eliminate direct animal waste discharges to surface waters.

Wastes used for nutrient value can be applied by various irrigation or broadcasting techniques. Several irrigation systems are hand moved, side roll, stationary big gun and traveling big gun dispersing systems. These methods require a large tract of suitable land with a compatible crop. Wastes provide crop nutrients, thus reducing chemical fertilizer costs, but land disposal may not be the best alternative if it causes nutrient or salt accumulations.

When using land application strictly at a disposal site, higher application rates allow the use of smaller land areas. Waste deposition is best used where land costs are low. Waste deposition is not a good method when land consists of steep slopes, impermeable or compacted soils. It should not be used when a potential for groundwater pollution exists but, unlike nutrient utilization, the land is of little other value so there is no need to worry about nutrient and salt accumulations provided no other uses are intended for the future.

Land applications for nutrient value are best used in accordance with fertilizer specifications. Application timing, placement and rate recommendations should be followed to minimize nutrient loss and maximize the benefits to crops.

- o Timing--The best time for application is determined by considering the soil type, climatic conditions and the crop. Wastes can be applied year round, annually or on an alternative time schedule. It is usually more costly to use annual application if storage facilities have to be built, though losses by runoff are reduced, daily spreading is eliminated and better use of nutrients results. Waste applications are frequently coordinated with other field operations. Wastes should not be applied during the winter months when land is frozen. Optimum application timing reduces erosion and nutrient transport and increases crop yield.

- o Placement--Application of wastes as a nutrient supplement will produce the best results when placed where it can be used by the plants. Disking or plowing places fertilizer in the root zone where it is available for plant use and less available for removal by runoff. Top dressing is applied after a crop has been established and runoff erosion reduced.

- o Rate--The quantity and frequency of waste application should be determined by matching waste nutrient content with plant nutrient requirements. Local SCS and extension service guidelines are available for application rates.

Other disposal system considerations include soil type, climate (temperature, precipitation), topography, crop and tillage methods. The U.S. EPA has developed effluent guidelines which outline the permissible feedlot discharge. To provide the suggested quality controls an alternative waste disposal system must be developed. These guidelines are generally for large feedlots which require permits as suggested by the NPDES. Control of smaller waste producing operations are covered by state and county controls. Most states promote optional use waste disposal systems. The use of these pollution control methods is made more attractive by offering state or federal funding through cost-share programs or tax credits.

DESIGN CONSIDERATIONS

The initial cost of a waste disposal system varies with the site, system type, equipment and labor costs. The investment costs include earthwork, land, and irrigation or spreading equipment. Other costs, such as fencing and engineering surveying should also be expected. The disposal site arrangement will directly influence the cost. Unless the disposal site is adjacent to the manure source, hauling and labor requirements will increase costs.

The cost of a land application system can include earthwork for a storage pond, and perhaps a settling basin; land costs of the storage area; and if the system is strictly a disposal system, the cost of the disposal site and irrigation or spreading equipment which may include a sprinkling unit, piping and a pump when dealing with liquid feedlot runoff.

The tables in this section were generated using an economic computer model to analyze feedlot waste disposal systems and their parameters (Miner et al., 1979). The cost values were supplied by specialists from the northwest U.S. All systems consist of a diversion structure to prevent clean water from entering the feedlot, a runoff collection structure, settling basin, storage pond and a disposal system. All systems were estimated for compliance with EPA´s 25 year-24 hour storm which may result in overdesigned disposal facilities. As shown under feedlot management, reducing runoff control to 90 percent will reduce costs by up to 40 percent.

The following table illustrates the minimum investment and annual pollution control cost in dollars per head of capacity for several feedlots (Miner et al., 1979). Smaller feedlot operation costs are strongly influenced by the installation of runoff control measures. Small feedlots may find it financially infeasible to install disposal facilities. State or federal cost-share programs may provide small or large operations with a method of financing control systems. The potential savings on fertilizer costs has not been calculated into the cost of land application disposal systems.

	Feedlot Size*					
	1 Acre		10 Acres		100 Acres	
Feedlot Location	Initial Costs	Annual Costs	Initial Costs	Annual Costs	Initial Costs	Annual Costs
Ames, IA	$22.91	$ 4.54	$ 8.41	$1.63	$ 6.59	$1.28
Astoria, OR	37.93	7.47	23.08	4.53	23.15	4.50
Bozeman, MT	20.81	4.11	6.70	1.27	4.91	0.92
Corvallis, OR	25.58	5.06	11.12	2.15	9.65	1.88
Experiment, GA	23.40	4.73	8.69	1.83	8.16	1.67
Lubbock, TX	21.85	4.29	7.52	1.42	5.68	1.06
Pendleton, OR	17.74	3.48	3.65	0.70	1.84	0.35

*Assumes a feedlot capacity of 200 head per acre. Least cost disposal system, all year pumping, hand move irrigation system. 1977 cost data used for analysis.

O & M needs for land application waste disposal systems are relatively high. The O & M requirements of the system would be met by the operator. Operating costs of a complete livestock facility include interest and depreciation, maintenance (equipment, earthworks), taxes, insurance, labor and energy. One study reported that annual storage and land applications will increase farm operation costs by about 15 percent compared to frequent applications corresponding with normal tillage operations, requiring no long-term storage facility (IJC, 1977).

The following table illustrates the annual operating cost in dollars per head of capacity for various irrigation systems (Miner et al., 1979). The data are for Ames, Iowa, at a set pumping rate of 0.27 acre-inch per feedlot acre-day, applying effluent to hay crop without winter disposal. The table shows that the more mechanical, high technology systems are more expensive.

	Feedlot Size*		
Irrigation System	1 Acre	10 Acre	100 Acre
Hand move	4.57	1.64	1.30
Side roll	--	1.72	1.34
Big gun	5.13	1.69	1.41
Travel big gun	--	--	1.42

*Assumes feedlot capacity of 200 head per acre. 1977 cost data used in computer analysis.

The following table was developed to show the minimum annual pollution control cost in dollars per head of capacity for Ames, Iowa, at a pumping rate of 0.27 acre-inch per feedlot acre-day and hand move irrigation (Miner et al., 1979). Management policies are varied to show how cost varies by crop and that systems with more frequent field applications tend to be cheaper. Disposal policies are varied to show the cost difference between nutrient utilization (200 lbs. nitrogen/acre) and waste deposition (1,200 lbs. nitrogen/acre, land costs included).

	Feedlot Area (acres)*		
Management Policy	1	10	100
Nutrient Utilization			
- All year disposal	4.57	1.64	1.30
- Corn crop, apply to crop	4.92	1.96	1.50
- Corn crop, apply to crop and post harvest	4.72	1.78	1.42
- Hay crop, apply to crop and winter months	4.54	1.64	1.43
- Hay crop, apply all year except winter months	4.54	1.63	1.28
Waste Deposition			
- All year disposal	5.08	2.20	1.86
- Hay crop, apply all year except winter months	5.08	2.22	1.86

*Assume feedlot capacity of 200 head per acre. 1977 cost data used in computer analysis.

The initial costs of using storage treatment as a waste disposal method will vary. Costs include excavation and land components. Generally, they are feasible only when land values are extremely low. Treatment lagoon capital costs were estimated between $300-$1100 per liter/sec of influent excluding land costs (IJC, 1977).

O & M needs are met by the system operator. Storage methods require less operation costs than land application methods, but have much higher maintenance needs. Besides maintenance of the earthen structure, accumulated sediments must be removed periodically to retain the facilities' effectiveness. Treatment lagoon O & M costs were estimated between $3.95-$5.50/1,000 cubic meters (IJC, 1977).

Most livestock waste disposal systems are designed for ease of development and use. Cases where difficulties in use occur can often be solved by applying an alternative system or altering the existing system components. The flexibility of livestock waste disposal systems allows a system to be tailored to the individual needs of each site.

COLLECTION SYSTEM MANAGEMENT

INFILTRATION

DESCRIPTION AND PURPOSE

Infiltration is an important component in agriculture collection system management. Infiltration removes excess surface water and enhances groundwater supplies. The soil surface, drainage system or detention facility can all be designed to promote infiltration. Leaving a rough soil surface retains runoff, allowing greater amounts of water to infiltrate. Some roughened surfaces also dissipate energy and reduce soil erosion. Infiltration drainage uses grass lined or gravel filled ditches to direct runoff while allowing infiltration. Subsurface drains can be applied to remove excess water without erosion. Pervious detention facilities in the form of basins, ponds and seepage areas are also used to promote infiltration.

The purpose of applying practices that enhance infiltration is to reduce runoff volumes which results in lower peak flows, less erosive damage and lower surface water sediment loading. Percolating stormwater through the soil layers provides a natural filtration process that removes many pollutants. Further details can be found in the Urban-Infiltration section.

ENERGY DISSIPATION

Energy dissipation practices are needed when topography, precipitation and drainage characteristics create highly erosive flows. Energy dissipation methods include rough surfaces, diversions and grade stabilization structures (drop structures, check dam). Energy dissipation practices are used to lower the flow velocity and reduce the erosive forces of runoff for the purpose of preventing soil erosion and the resulting addition of sediments to surface waters.

Rough soil surfaces provide slight levels of energy dissipation for overland flows. On agricutlural lands leaving a field rough with large soil clods or crop residues during periods of high runoff can be an effective way to reduce runoff sediment transport capacity. Crop residues will reduce erosion by stabilizing the soil surface, as discussed under alternative tillages, as well as dissipating the erosive forces of the runoff.

Diversions deal with overland flow, dissipating energy on sloping fields. Diversions are placed on slopes to direct runoff to a stabilized route that will cause lower erosion rates. Details on agricultural uses for diversions are discussed in the following section.

Grade stabilization structures such as drop structures or check dams are placed directly in the waterway to reduce bank erosion and downcutting. The grade stabilization methods discussed in the urban section can be applied to agricultural property.

ROUGH SURFACES

Details on rough surfaces and grade stabilization structures can be found in the Urban-Energy Dissipation section.

GRADE STABILIZATION STRUCTURES

Details on grade stabilization structures can be found in the Urban-Energy Dissipation section.

DIVERSION

Description and Purpose

Diversions are channels or berms designed to collect sheet and concentrated overland flow and to direct it along a stabilized route at nonerosive velocities. Diversions are applied in many different situations but the purpose is always to collect and direct water to a specific location. In agricultural areas, the two main uses of diversions are to prevent erosion by keeping runoff away from erodible areas or to collect polluted water and direct it to a storage or disposal area.

Diversions are usually constructed perpendicular to runoff. Berms are well compacted earth embankments constructed on a slope. Diversion channels are shallow trenches or ditches constructed at the top or bottom of a slope. A commonly applied type of diversion is a berm and channel combination, wherein channels are constructed laterally across a slope with a supporting ridge protecting the lower side. The embankment ridge can be conveniently constructed with materials from the excavated ditch.

Target Application

Diversions are applied to control a variety of target pollutants. Diversions applied to erodible land prevent the movement of sediments and associated pollutants into surface waters. Diversions constructed as part of a feedlot management plan are aimed at controlling phosphorus, nitrogen, organic matter and pathogens.

Diversions are applied when runoff on sloping fields is causing sheet erosion or gullying; when hillside runoff may damage low-lying property; when runoff towards a feedlot needs to be diverted; or when feedlot effluent may enter a surface waterway. Temporary diversions are applied on slopes during construction to prevent increased erosion of a disturbed area or to keep excess water from inteferring with the construction process. Permanent diversions are installed to protect agricultural lands from excess water according to a comprehensive farm management plan.

Effectiveness

Diversions improve water quality by controlling the pollution source. Sediment loadings are decreased by reducing runoff on erosive soils and by controlling the runoff´s gradient, velocity and sediment transporting ability.

Diversions are preventative measures which keep additional solids from being transported to waterways via runoff. Haith and Loehr (1979) determined that diversions were highly effective at controlling runoff detachment in a gully but they had little effect on controlling pollution from any other source. Diversions can also be used to direct polluted runoff to storage or disposal areas to prevent it from entering surface waters. As part of an overall feedlot management plan, a well designed diversion is effective at containing polluted effluent though surface water may still be polluted at a different stage such as runoff after effluent land application.

Planning Considerations

Diversions should be located to minimize interference with or damage by cultivation operations. The choice of location will depend on outlet conditions, topography, land use, development layout, slope length and soil type. Specific design and installation considerations include adequate capacity for peak runoff values and storm frequencies; limited flow velocity depending on channel lining and soil type; cross sectional shape with acceptable height, width and side slope values; diversion lining, grade and alignment; and outlet conditions.

To provide the best results, excess water must be diverted to a stable outlet at a nonerosive velocity. Common methods of disposing of the runoff are discharge into a stabilized ditch, slope drainage, or discharge at a nonerosive velocity through a level spreader, sediment control device, or to an undisturbed stabilized area.

Planning the placement of a diversion requires some knowledge of effective diversions. A poorly placed diversion will not reduce erosion but may actually promote it. For instance, a diversion may intercept sheet flow but discharge concentrated flow, possibly creating deep gullies.

The ease with which diversions are developed and used depends on the requirements of the site. Diversions should be constructed to provide a positive grade to assure drainage. Unless the diversion slope is steep enough to dispose of runoff, water may be stored around the diversion or sediment accumulation may increase. Water storage would not only require space and increase erosion around the diversion, it would promote seepage which causes soil instability. The diversion slope should not be too great so as to avoid erosion due to high flow velocities.

Steps should be taken to preserve the diversion. Any diversion that will be operating for any length of time should be stabilized with temporary or permanent seeding, mulching or structural means. To prevent failure, berms and dikes should be adequately compacted.

Diversions can be applied as an alternative to a more costly runoff control system, such as terracing or diversions. They can also be integrated with other MPs to provide more effective controls. They may be placed above a terrace system or combined with strip cropping or contouring to make these methods more effective by shortening the slope length and reducing the quantity that must be controlled by a soil conservation method.

The best uses of a diversion provide benefits in addition to nonpoint source pollution control. Diverting runoff away from potential or existing gullies reduces soil losses and damage to fields. Diverting runoff from feedlot areas reduces the volume of polluted water that must be controlled. It is more economical to deal with a concentrated effluent then to allow additional runoff to dilute the animal wastes. To convey water down a slope, diversions direct water laterally across the slopes, increasing the land distance and travel time. The benefits of a reduced peak flow downstream are reduced streambank erosion and scouring.

Design Considerations

Diversion costs are site specific; therefore, it is difficult to provide an estimate on the initial cost. The cost will depend on the diversion design which indicates the types and amounts of mechanical and manual labor. The cost of land is not included though the placement of diversions removes land from crop production. The water quality management plan for the Root River Watershed (Wisconsin) estimated in 1979 costs the average capital cost for a rural diversion at $1.75 per foot (SEWRPC, 1980). Another study (IJC, 1977) compiled a capital cost range for two types of diversions as follows:

Method	Diversion Costs
Diversion ditch	\$2.70-8.05/cubic yard
Dike	\$0.95-1.75/cubic yard

Diversion O & M needs include periodic inspection and repair. Maintenance will be needed to check diversion erosion and sedimentation. Repairs of scoured diversions should be made promptly. If vegetative stabilization has been used, regular maintenance is needed such as mowing or weed control. Sedimentation interferes with the operation of the diversion; therefore, periodic removal of accumulated sediments is essential. The cost will be dependent on the sediment accumulation rate, type of scouring and erosion rate.

As a component in conservation system management plan, diversions may qualify for technical or financial assistance. Technical assistance from organizations such as the Soil Conservation Service is provided to aid in development and use. Diversions should be designed and implemented to best suit the areas' characteristics and environmental needs. As a pollution control practice, diversions may qualify for financial assistance through tax credits or federal cost-sharing funds.

To prevent construction difficulties, limitations on diversion use should be followed. Difficulties may arise from unstable outlets, or from site, slope or soil problems. Unstable outlets will allow erosion to occur at the end of the diversion. Diversions should only be used to control runoff from small drainage areas. They should not be installed on or below extremely steep slopes unless they have been previously stabilized. Diversions should not be substituted for grade stabilization structures used to obtain slope stability. Construction activitites may accelerate erosion and sedimentation by disturbing the soil surface. It may be necessary to implement sediment controls if construction procedures cannot be altered to prevent heavy soil loss.

WATERWAY STABILIZATION

As a source of nonpoint source pollution, waterways are critical areas. They conduct concentrated flows making them a particularly vulnerable site for erosion. Besides the proximity to flows capable of detaching and transporting sediments, pollutants from streambank erosion or bed scouring are delivered directly into the waterway. To eliminate nonpoint source pollution in a agricultural collection system, the waterway, streambank, and immediately surrounding area should be stabilized.

BUFFER STRIP

Description and Purpose

A buffer strip is a permanent vegetated area surrounding a field or surface water body. The purpose of establishing a buffer zone is to prevent the erosion and transportation of sediments to surface waters. Erosion is prevented in the critial area surrounding streams and ponds by maintaining established vegetation which reduces runoff velocity and provides an erosion-resistance surface cover. Streambanks which are damaged by overland flow may benefit from the reduced velocites. A buffer zone prevents cultivation or disturbances at or near streambanks. Buffer strips also provide some filtering of sediment.

Target Applications

The target pollutants controlled by buffer strips are sediments and associated pollutants. This method also may have some effect on nutrients adsorbed to sediments. Buffer strips should be applied to all areas immediately adjacent to permanent waterways. These vegetated areas can also be placed around fields or animal grazing areas to provide filtering and velocity control.

Effectiveness

Buffer or filter strips are most effective on sediment and solid-phase nutrients. These strips generally have little or no effect on soluble chemicals. The effectivenees of filter strips on water quality is dependent on the buffer strip width, vegetation type and runoff volume.

Buffer strips are very effective at preventing erosion, but only erosion of the strip area. Their efficiency at removing sediments by filtering runoff is not as impressive while the effectiveness of preventing erosion by dissipating erosive energy and slowing runoff velocity is very low. A summary of studies found buffer and filter strips capable of reducing TSS by 0-50 percent (Oberts, 1981).

Planning Considerations

Buffer strips are best used on critical areas around surface waters. Buffer strips between croplands and lakes or streams protect surface water quality by slowing down overland flow and filtrating field runoff. Buffer strips are also used to prevent bank damage by operating heavy cultivating equipment too close to the streambank edge.

The best use of a buffer strip to control sediments requires that it be properly designed and maintained. The effectiveness is highly dependent on the vegetation type, buffer strip width and runoff volume. The easiest method of application is to leave a strip of existing vegetation where an area adjacent to a waterway is being cleared. In most cases, small strips are left along fence, stream and wetland borders and it may only be a case of widening existing strips to provide an effective buffer area.

Design Considerations

The cost of establishing a buffer strip includes establishment costs and land costs. Establishment costs are made up by seeding and the addition of chemicals (nutrients and pesticides) as needed. Land costs represent the value of the property lost by removing it from crop production. Buffer strips are usually a very economical method of controlling sediment from agricultural land.

GRASSED WATERWAY

Description and Purpose

A grassed waterway is a broad shallow depression, vegetated with grass. The purpose of a grassed waterway is to conduct concentrated flows without allowing erosion damage. Vegated surfaces are capable of reducing runoff velocities, filtering runoff contaminents and eliminating surface erosion.

Target Applications

The grassed waterway target pollutants are sediment and associated pollutants generated from erosion. Grassed waterways are applied when there is a need for a stabilized channel or outlet to deal with concentrated flows. Grassed waterways cannot be applied to control a continuous flow or runoffs with extremely high sediment concentrations. Grassed waterways are used in fields to convey flows that might create gullies in an unstabilized channel. They also are used as a stabilized outlet for runoff collected in terraces, graded rows or contour systems.

Effectiveness

Grassed waterways can be developed to provide a stabilized drainage system for agricultural fields. They are effective at controlling runoff that might otherwise cause severe gullying and soil loss which would result in high sediment loadings to surface waters. Vegetation is very effective at eliminating the source of pollution, in this case channel erosion, but it is much less effective at filtering existing pollutants. Even though vegetation can under some circumstances nearly eliminate erosion, the overall effect on water quality is fairly low since waterway vegetation only prevents erosion "in" the channel.

In a broad parabolic channel with good cover, sediment delivery can be reduced 10-15 percent. A narrow channel with poor vegetative cover may only provide 0-10 percent sediment delivery reduction (Oberts, 1981).

Planning Considerations

The proper design of a grassed waterway is essential to the effectiveness as an erosion control method. These are best applied as broad, shallow channels with gentle side slopes and low gradients. The channel should be shaped or graded to aid vegetation establishment across the whole cross-section. A parabolic shape is frequently used since it provides gentle slopes that are relatively stable and can be crossed by most farm equipment without damaging the waterway banks.

Grassed waterways are designed to convey runoff at low velocities. By considering the soil condition and runoff quantity, the channel gradient can be designed to drain runoff at a rate that does not cause erosion or allow sediments to settle. Accumulations of sediments in a waterway may damage vegetation. The drainage rate should be designed to prevent long periods of constant flow, and the gradient should be steep enough to prevent standing water, both of which may damage vegetation.

Because of the cost, structural linings and outlet protection are usually applied only when vegetation is not adequate. Instances where structural measures may be needed include long flow duration, high flow velocity, erodible soils or steep slopes. Vegetation cannot withstand extremely high velocities or flows with high erosive energy typically found below culvert or tile outlets. Riprap is a common structural material used to provide stabilized channel lining. For details, refer to the Urban-Erosion Control-Drainageway Protection section.

Design Considerations

Grassed waterways represent a relatively inexpensive type of stabilized drainage system. Channels designed to utilize existing natural depressions may require slight regrading or shaping and man-made channels require minimal amounts of excavation.

Sodding or seeding costs have been estimated in the area of $1.30 per square yard (Stanley Consultants, 1976). Additional cost considerations include the loss of a small amount of land for crop production; savings in repair of gully damage; and a reduction in drainage ditch dredging costs.

O & M needs for grassed waterways are essential to maintain their effectiveness at controlling erosion. The major maintenance problem is to keep a good cover growing. Areas with poor vegetative cover will require seeding to improve its erosion control ability. Periodic mowing and occasional fertilization are needed to maintain adequate vegetative soil coverage.

One problem that may disrupt the use of a grassed waterway is the possibility that herbicides washed from a field may destroy the channel vegetation. A second difficulty that may arise with construction of a waterway is the possiblity of interference with machine operation. Maneuvering large equipment along grassed waterways could be inconvenient, though working around a smooth shallow grassed depression would be easier than a gully.

While channel vegetation is being established, water flow into the channel can damage the cover. One method of handling difficulties with grass establishment is to stage the construction of the drainage system. For instance, a grassed waterway used as an outlet for a terrace system would be established before the terrace system was constructed. Mulches and erosion control mats may be applied to protect vegetation during the establishment period. Sod is more expensive then seeding, but it is less vulnerable while the grass cover is being started.

STREAMBANK STABILIZATION

Description and Purpose

Streambanks are stabilized with either vegetative or structural protection. Vegetative streambank protection measures included retaining existing vegetation, seeding, planting, sodding, mulching and erosion control mats. Structural streambank protection measures include grade stabilization structures, riprap, gabions, deflectors and revetments.

The purpose of streambank stailiziation is to prevent scouring of banks and control meandering. By preventing bank erosion, stabilization methods reduce the addition of sediments to the stream. The control of meandering protects adjacent agricultural lands from property loses due to a moving streambed.

Target Applications

The target pollutant of streambank stabilization is suspended solids. Stabilization measures are aimed at preventing the erosion of bank soil into the surface water.

Streambank stabilization can be applied to any stream, river, ditch, pond or lake where bank erosion is considered a physical or environmemtal problem. Bank erosion may interfere with the adjacent land use if bank loss or meandering becomes extremly severe. Bank erosion results in large additions of sediments directly to the waterway. Stabilization will reduce the accumulation of solids in waterways, result in lower dredging requirements and fewer problems with reduced channel capacity.

Vegetative measures can be applied when noncritical levels of erosion occur. Vegetation should not be applied to steeply sloping banks, highly erosive soils or waterways with high velocity flows. Structural measures are usually applied when the use of vegetation is not feasible. Vegetation is often recommended in conjunction with structural measures.

Effectiveness

The effectiveness of streambank stabilization at reducing erosion depends on the methods employed, the extent of protection and the stream profile. Nearly 100 percent of all bank erosion sediment ends up in the surface water; therefore, any reduction in erosion will directly reduce the suspended solids in the stream water.

In some cases, vegetation is highly effective at reducing bank erosion and soil loss into a waterway. Stabilization effects are low immediately after planting but increase as vegetation becomes established. The actual benefits are site specific, but generally vegetation works best on mild slopes, less erosive soils and low flow velocities. Structural measures have varying degrees of effectiveness. The principal purpose is to reduce erosion at a specific critical point. Structural methods correctly implemented can do this but often at the expense of another section of streambank. For example, a revetment protecting a sharp bend reduces erosion of a critical point at the expense of the opposite bank or stream bed. The sediment loading is not reduced, just transferred to a less critical section of the stream bed.

Planning Considerations

Streambank stabilization is best used by careful selection, design and installation of a suitable measure. Within the vegetative and structural categories, several diverse alternatives are available for consideration. The choice is made by considering economic factors, site charateristics and effectiveness. Factors that should be considered when designing a protective measure are soil type, bank steepness, precipitation, flow velocity, seepage, overland flow and adjacent land use.

Further information can be found in a discussion on planning considerations for vegetative and structural measures in the Urban-Erosion Control-Streambank Stabilization section.

Design Considerations

The cost of streambank stabilization is determined by the measures used. The cost will be much lower when applying vegetative rather than structural practices. The Council's report "Water Resource Management: Nonpoint Source Pollution Technical Report" summarized 1982 management practice costs for the Metropolitan Area. For a rural watershed it determined channel stabilization costs would be $10-60/foot (Oberts, 1982).

The O & M needs will vary depending on the type of measure, vegetative or structural. Vegetation requires little or no maintenance to remain effective. If the chosen plant type is compatible with the bank characteristics, maintenance needs such as replanting will be unnecessary. Structural measures often require frequent O & M applications. To maintain the bank stabilizing benefits, structures require increasing repairs as they age. Once vegetation is established, it provides long-term protection with minimal maintenance. Structural measures provide immediate protection but have a limited life span and high maintenance requirements.

Construction difficulties occur when vegetating a steep or critically erosive area. Unless the bank is stable during the period of vegetation establishment, vegetation will fail. Combining vegetation and structural methods allow stabilization of critical areas using structural methods so that vegetation may become established. Placing a plant at the wrong water level zone will result in vegetative failure. Flow level fluctuations must be correctly determined since vegetation able to withstand periodic submergence will not necessarily survive constant flows.

Difficulties in construction depend on the type of structure used. Materials must be durable, concrete should hold up in freeze/thaw and rocks should not disintegrate. Rocks that are too small will not remain where placed. Rough handling of liners will tear or displace them.

The ease with which vegetative measures are developed and implemented encourages use of this erosion control method. Vegetating a streambank can be implemented as a community volunteer project. Vegetation is perhaps the method most compatible with natural stream characteristics. An alternative to introducing new vegetation is to maintain existing plants or supplement them to provide erosion control.

Structural methods require comprehensive planning to determine the full impacts of stabilizing one section of bank. Miscalculations can increase scouring in other areas, increase flooding or prove ineffective for reducing erosion on the critical bank

DETENTION

WETLANDS

DESCRIPTION AND PURPOSE

The preservation of wetlands in agricultural areas uses an existing resource to control nonpoint source pollution. Preserving natural detention areas is an economical way to control agricultural runoff, since little construction or maintenance is required. The purpose of preserving a wetland is to keep an area that can improve water quality by trapping or transforming pollutants using physcial, chemical and biological processes. Further information can be found in the Urban-Other-Wetland section.

PONDING

DESCRIPTION AND PURPOSE

Ponding can be used to store runoff from agricultural land. Detention is created in a constructed depression, natural depression or waterway. Ponding is formed by excavating a basin, by constructing an embankment, by constructing a barrier or dam across a waterway, or by installing outlet controls.

A pond on agricultural land can be designed to promote detention, infiltration or sedimentation. Detention ponding controls the discharge rate from a storage area and stores the volume of runoff that exceeds the design discharge rate. The purpose of detention ponding is to delay runoff, which then reduces the peak flow resulting in less erosive conditions and slower velocities. Detention ponds can be constructed for additional purposes such as livestock watering or irrigation.

Infiltration ponds are designed to promote percolation of the detained water by constructing a highly pervious basin bottom or lengthening the detention time. The purpose of an infiltration pond is to reduce the flow volume and recharge groundwater supplies. By reducing the runoff quantities infiltration ponds also lower flow levels and velocities which result in reduced erosion as well as reduced pollutant delivery to the waterway.

Sedimentation ponds are designed to trap and retain sediments. The pond removes suspended solids by detaining runoff for periods long enough to allow settling due to gravity. The purpose of a sedimentation pond is to provide direct removal of pollutants in agriculture runoff water before discharging into a waterway.

TARGET APPLICATIONS

The target pollutants of agricultural ponding practices are sediment, nutrients and organics. Since it is difficult to control solubles or fine-grained particles, the target pollutants are medium- and coarse-grained sediments.

Agricultural ponds should be integrated into the areal drainage system. Ponds can be used when uncontrolled runoff from crop or livestock areas would degrade surface water quality. Ponds placed below a sloping disturbed area to collect runoff are called base-of-slope detention. Ponds are also used to collect runoff from livestock areas or pastures where organic content is high. Ponds can be designed for multipurpose use, not only to collect polluted water but as an irrigation storage pond or a pond for watering animals.

Ponds can be applied when a satisfactory site is available. A pond requires land that might otherwise be placed in crop production. The topography and drainage system should be compatible with the pond's operational needs. The type of pond and its placement should be designed according to the specific site limitations.

Infiltration ponds cannot be used on heavily loaded runoff water, since large volumes of settling solids will quickly destroy the basin's percolating ability, and unwanted contaminants might seep into the groundwater system. Infiltration is most effective in areas with permeable, well drained soils.

Sedimentation ponds are used when runoff contains heavy sediment loads that will negatively impact downstream waterways and property. Unless heavy sediment loads are removed from runoff, the solids may be deposited downstream, clogging the waterway or covering land with silt, and degrading the water quality. Sedimentation ponds are also applied prior to discharge into an infiltration area or wetland.

EFFECTIVENESS

The effectiveness of a pond at improving surface water quality will depend on the basin design. Basins designed to infiltrate or detain runoff will not improve water quality as well as basins designed strictly to allow settling.

The following values represent the approximate reduction of pollutants due to the installation of an agricultural detention pond (Oberts, 1982). These values demonstrate the general range for a pond that is well designed and maintained. The actual water quality benefits for a specific pond will be site specific.

Pollutant	Percent Reduction
TSS	75-90
Nutrients	50-75
COD	40-50

PLANNING CONSIDERATIONS

The use of ponding depends on the availability of land, land use, target pollutants and land characteristics. Ponding requires a relatively large area of land on which water is collected and detained. Detention is an essential component of a feedlot waste management system. Ponding of runoff from cultivated cropland protects the water quality of downstream areas, but is not an alternative to erosion control practices for preventing soil losses from agricultural fields.

To provide the best use of detention ponding, the facility design must be appropriate. The detention pond design includes inlet and outlet structures; embankment slopes; and basin shape and size. Detention ponds are created by using a restricted outlet to control the discharge rate into the drainage system. The pond must be designed to deal with inflow quantities which depend on the design storm (frequency, duration, discharge) and the surrounding area (topography, land use, sediment loading rate, drainge area).

When designing a settling basin capable of providing the required treatment, capacity considerations must be made. The required storage volume can be calculated by considering sediment loading factors and runoff volume requirements. The basin size should allow runoff detention for a period of time capable of providing the desired settling. The facility should be protected against erosion. Earthen embankments rquire rapid vegetative stabilization, and outlets should be provided with outlet protection such as riprap. The inlet and outlets should be designed to handle overflow without damage.

DESIGN CONSIDERATIONS

The initial cost of a sedimentation basin will vary according to site and design specifications. The site specifications, location and topography will vary the amount of excavation and the embankment height required. The design specifications, materials (concrete, earth, asphalt), volume capacity and additional use of detained runoff will also vary the cost.

Higher initial costs will occur when larger amounts of construction are required in excavation or embankment construction, or when the design requires additional construction to provide infiltration, sedimentation or treatment. Basin materials will also control the cost; earthen basins have been reported costing up to four times less than comparable concrete facilities. The following 1982 rural detention costs were summarized for the Twin Cities, Minnesota (Oberts, 1982):

Detention Type	Cost ($/acre-foot)
Rural detention	$25-250
Wetland/lowland detention	25-100
Rural watershed nonstructural detention	50-250
Rural lakes nonstructural detention	20-850

Land costs are often not included in the initial cost of a detention pond. Land costs will vary depending on property availability and surrounding land use. In many cases a sizable area of land will be taken out of crop production; the lost revenue is considered as part of the initial cost of installing a pond.

The ease of development and use will depend on the use of proper design and maintenance procedures. Due to the high nutrient concentrations in some agricultural runoff, detention ponds may become extremely eutrophic. Difficulties with algae growth, insect breeding and accumulating sediments may discourage the use of ponding. Lack of maintenance or improper design might cause resuspension of sediments during large storm events, which would eliminate the prime environmental benefits derived from installing a pond.

O & M needs include the timely removal of sediments, debris, vegetation and repair of the pond structure. The frequency of sediment removal will be dependent on the settlement rate. The private property owner is responsible for providing pond maintenance.

BIBLIOGRAPHY

Athayde, D.N. and A. Waldo, 1977. The Urban Stormwater Runoff Presentation, 208 seminars. EPA, Nonpoint Source Branch, Washington, D.C., 63 pp.

Brandt, S., 1983. No-Till Planting Gets Off the Ground. Minneapolis Star and Tribune, April 18, 1983, p. 3B-4B.

Chan, E., T.A. Bursztynsky, N. Hantzsche, and Y.J. Litwin, 1982. The Use of Wetlands for Pollution Control. EPA-600/2-82-086, 276 pp.

Crosson, P., 1981. Conservation Tillage and Conventional Tillage: A Comparative Assessment. Soil Conservation Society of America, Ankeny, Iowa. 39 pp.

Erdmann, J.B., E.J. Johnson, N.C. Wenck, and E.A. Hickok, 1981. Final Report Minneapolis Chain of Lakes Research and Demonstration Project. Minneapolis, Minnesota. EPA No. S-804260-01, 239 pp.

Field, R., H. Masters, and M. Singer, 1982. An Overview of Porous Pavement Research. Water Resources Bulletin, Vol. 18 (2), p. 265-270.

Fitzpatrick, M., M. Koplan, E.I. Selig, R. Howe, N. White, and A. Waldo, 1977. Preventive Approaches to Stormwater Management. EPA-440/9-77-001, 207 pp.

Haith, D.A., and R.C. Loehr, 1979. Effectiveness of Soil and Water Conservation Practices for Pollution Control. EPA-600/3-79-106, 479 pp.

Hemmer, R.F., and D.L. Forster, 1978. Farmer Experiences with Alternative Tillage Practices in the Western Lake Erie Basin. U.S. Army Corps of Engineers, Buffalo District, 54 pp.

Hickok, E.A., M.C. Hannaman, and N.C. Wenck, 1977. Urban Runoff Treatment Methods, Volumne I: Non-Structural Wetland Treatment. EPA-600/2-77-217, 131 pp.

Honey Creek Joint Board of Supervisors, 1981. Honey Creek Watershed Project: Tillage Demonstration Results 1980. U.S. Army Corps of Engineers, Buffalo District, 87 pp.

International Joint Commission, 1977. Evaluation of Remedial Measures to Control Non-Point Sources of Water Pollution in the Great Lakes Basin. International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG), Ontario, Canada, 197 pp.

International Joint Commission, 1978. Environmental Management Strategy for the Great Lakes System. International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG), Ontario, Canada, 134 pp.

International Joint Commission, 1983. Practical Tips on the Large-Scale Use, Storage and Disposal of Pesticides. IJC Regional Office, Ontario, Canada. Focus on Great Lakes Water Quality, Vol. 8 (4), p. 11.

Journal of Soil and Water Conservation, 1983. Conservation Tillage: A special issue. May-June 1983, Vol. 38 (3), p. 134-319.

Kuhner, J., W.W. Walker, and J.J. Wineman, 1978. Methodology for Evaluating Agricultrual Best Management Practices (BMPs). EPA, Research and Development Division, PB 290742, p. 88-104.

Lager, J. A. and W. G. Smith, 1974. Urban Stormwater Management and Technology: An Assessment. EPA 670/2-74-040.

Lager, J.A., W.G. Smith, W.G. Lynard, R.M. Finn, and E.J. Finnemore, 1977. Urban Stormwater Management and Technology: Update and User's Guide. EPA-600/8-77-014, 330 pp.

Leiser, C. P. 1974. Computer Management of a Combined Sewer System. EPA-670/2-74-022.

Logan, T.J., and J.R. Adams, 1981. The Effects of Reduced Tillage on Phosphate Transport from Agricultural Land. U.S. Army Corps of Engineers, Lake Erie Wastewater Management Study, 29 pp.

Lynard, W.G., E.J. Finnemore, J.A. Loop, and R.M. Finn, 1980. Urban Stormwater Management and Technology: Case Histories. EPA-600/8-80-035, 354 pp.

Metropolitan Association of Soil and Water Conservation Districts, 1973. Urban Erosion Control Handbook, Minnesota. MASWCD, 136 pp.

Metropolitan Council, 1981. Transport of Pesticides, Unpublished Staff Report, Minnesota, 28 pp.

Metropolitan Council, 1982. Surface Water Management: Nonpoint Source Pollution and Storm Water Runoff. Water Resource Management Development Guide: Part 2, p. 103-166.

Metropolitan Council, 1983a. Surface Water Management: Simplified Modeling for Watersheds. Metropolitan Council Report No. 10-83-130, 38 pp.

Metropolitan Council, 1983b. Surface Water Management: Evaluation of Nationwide Urban Runoff Program (NURP). Metropolitan Council Report No. 10-83-127, 55 pp.

Michigan Department of Natural Resources, 1975. Michigan Soil Erosion and Sedimentation Control Guidebook. Mighigan DNR, Bureau of Water Management.

Miner, J.R., R.B. Wensink, and R.M. McDowell, 1979. Design and Cost of Feedlot Runoff Control Facilities. EPA-600/2-79-070, 144 pp.

Minnesota Pollution Control Agency, 1981. Animal Feedlots. MPCA, Division of Water Quality, 32 pp.

Mitchell, J.K., J.C. Brach, and E.R. Swanson, 1980. Costs and Benefits of Terraces for Erosion Control. Journal of Soil and Water Conservation, Sept.-Oct. 1980, Vol. 35 (5), p. 233-236.

Moreau, D.H., and T.F. LaPointe, 1979. An Evaluation of Small Scale Dispersed Technologies for Managing Urban Stormwater Quality. Water Resources Research Institute of the University of North Carolina, UNC-WRRI-79-138, 63 pp.

Oberts, G. L., 1977. Water Quality Effects of Potential Urban Best Management Practices: A Literature Review. Department of Natural Resources, Technical Bulletin No. 97, Madison, Wisconsin, 24 pp.

Oberts, G.L., 1980. Urban Runoff Management Practices (A Technical Paper). Staff report, Metropolitan Council, Minnesota. 37 pp.

Oberts, G.L., 1981. Framework for Applying Management Practices. Water Quality Management Report No. 5, Metropolitan Council, Minnesota, 46 pp.

Oberts, G.L., 1982. Water Resource Management: Nonpoint Pollution Technical Report. Metropolitan Council, Minnesota. Publication No. 10-82-016, 256 pp.

Payne, G.A., M. A. Ayers, and R.G. Brown, 1982. Quality of Runoff from Small Watersheds in the Twin Cities Metropolitan Area - Hydrologic data for 1980. U.S.. Geological Survey Open-file Report 82-504, 289 pp.

Pitt, Robert, 1979. Demonstration of Nonpoint Pollution Abatement through Improved Street Cleaning Practices. EPA-600/2-79-161, 290 pp.

Pollard, R.W., B.M.H. Sharp, and F.W. Madison, 1979. Farmers´ Experience with Conservation Tillage: A Wisconsin Survey. Journal of Soil and Water Conservation, Sept.-Oct. 1979, Vol. 34 (5), p. 215-219.

Richards, D.L., and L.M. Middleton, 1978. Best Management Practices for Erosion and Sediment Control. Federal Highway Administration, Arlington, Virginia, Report No. FHWA-HD-15-1, 90 pp.

Richardson, D.L., R.C. Terry, J.B. Metzger, R.J. Carroll, and A.D. Little, 1974. Manual for Deicing Chemicals: Application Practices. EPA-670/2-74-045, 164 pp.

Scheib, W.L., R. Diedrick, E.P. Mueller, J. Hultgren, and A.R. Vaughn, 1976. Runoff, Erosion and Sediment Control Handbook, Minnesota. U.S. Department of Agriculture, Soil Conservation Service, 356 pp.

Seibert, P., 1968. Importance of National Vegetation for the Protection of the Banks of Streams, Rivers and Canals. In Freshwater, p. 35-67. Council of Europe, New York.

Seitz, W.D., D.M. Gardner, S.K. Gove, K.L. Guntermann, J.R. Karr, R.G.F. Spitze, E.R. Swanson, C.R. Taylor, D.L. Uchtmann, and J.C. Van Es, 1978. Alternative Policies for Controlling Nonpoint Agricultural Sources of Water Pollution. EPA-600/5-78-005, 338 pp.

Southeastern Wisconsin Regional Planning Commission, 1980a. A Nonpoint Source Water Pollution Control Plan for the Root River Watershed. SEWRPC, Community Assistance Planning Report No. 37, Waukesha, Wisconsin, 105 pp.

Southeastern Wisconsin Regional Planning Commission, 1980b. A Water Quality Management Plan for Lac La Belle. SEWRPC, Community Assistance Planning Report No. 47, Waukesha, Wisconsin, 126 pp.

Stanley Consultants, Inc., 1976. Urban Intermittent Point and Nonpoint Source Control Alternatives and Cost Information. Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, 87 pp.

U.S. Department of Agriculture, Agriculture Research Service, 1975. Control of Water Pollution from Cropland, Volume I: A manual for guideline development. EPA-600/2-75-026a, 118 pp.

U.S. Department of Agriculture, Soil Conservation Service, 1972. Erosion and Sediment Control Handbook for Connecticut. USDA-SCS, Storrs, Connecticut, 126 pp.

U.S. Environmental Protection Agency, 1980a. Water Quality Management Bulletin, Farmers and Clean Water: Working Together. EPA, Water Planning Division, p. 8, 14-24.

U.S. Environmental Protection Agency, 1980b. Seminar on Water Quality Trade-Offs: Point Source vs. Diffuse Source Pollution. U.S. EPA, Great Lakes National Program Office. EPA-905/9-80-009, 398 pp.

U.S. Environmental Protection Agency, 1982. Preliminary Results of the Nationwide Urban Runoff Program: Volume I (Final draft). EPA, Water Planning Divison, 118 pp.

Virginia Soil and Water Conservation Commission, 1980. Virginia Erosion and Sediment Control Handbook: Second Edition. Virigina, 554 pp.

White, C.A., and A.L. Franks, 1978. Demonstration of Erosion and Sediment Control Technology: Lake Tahoe Region of California. EPA-600/2-78-208, 406 pp.